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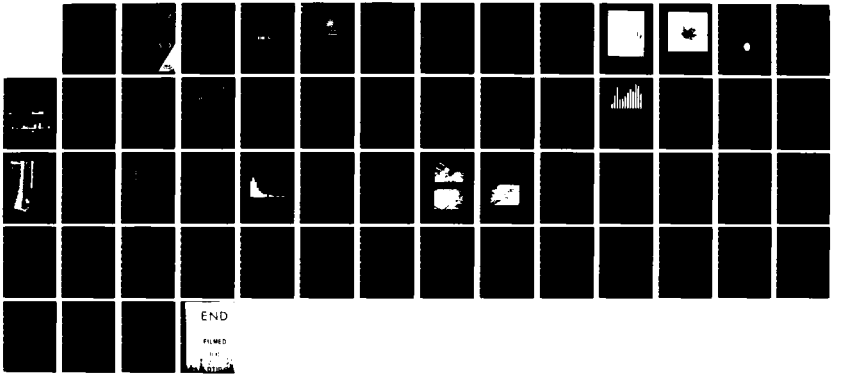

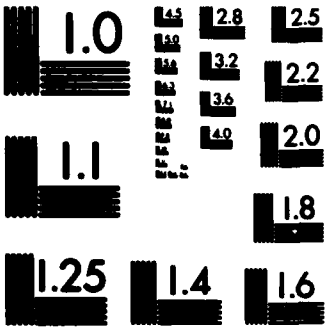

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AD-A134016

TROPICAL CYCLONES AFFECTING GUAM

(1671 - 1980)

by:

LT Robert C. Weir, USN

PREPARED BY

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A climatology of tropical cyclones passing within 180 nm of Guam is presented for the period 1948 to 1980. A review of all typhoons of the 1600's are included. The survey encompasses the frequency, behavior, meteorological effects and descriptive chronicles of Guam tropical cyclones. The major emphasis is on the period since World War II.

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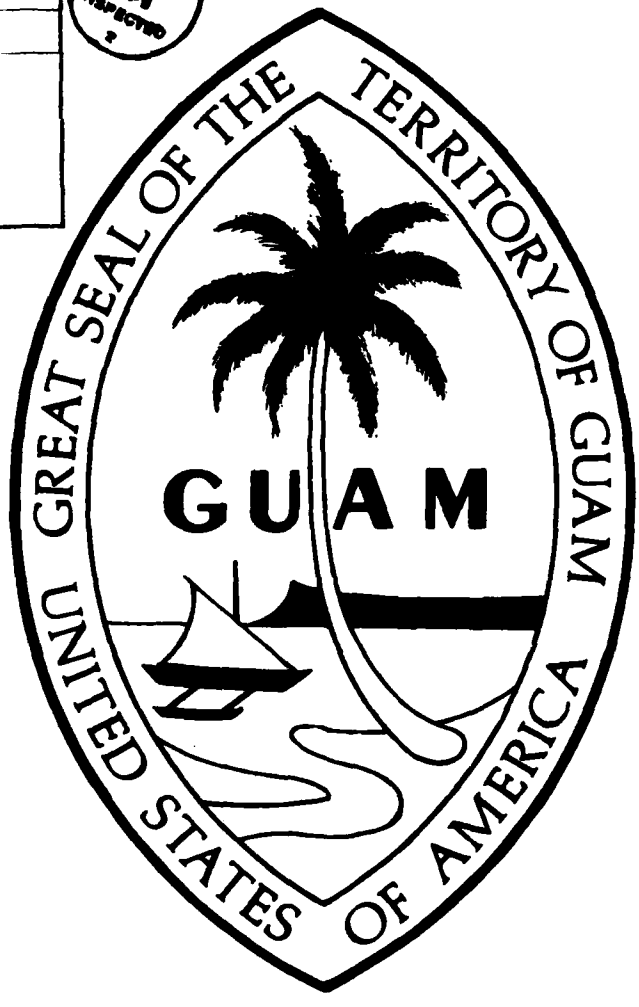

Following the typhoon of 1918, a surviving palm tree at the mouth of the Agana River later inspired the design of Guam's official seal, which was adopted in 1930. (From Carano & Sanchez, History of Guam)

CONTENTS

ABSTRACT

A climatology of tropical cyclones passing within 180 nm of Guam is presented for the period 1948 to 1980. A review of all typhoons affecting Guam is carried back to 1800 and some noteworthy typhoons of the 1600's are included. The survey encompasses the frequency, behavior, meteorological effects and descriptive chronicles of Guam tropical cyclones. The major emphasis is on the period since World War II.

ACKNOWLEDGEMENTS

The writer is indebted to the efforts of Holliday (1975). His technical note was the basic structure for this report and his exhaustive efforts in researching the historical record concerning tropical cyclones affecting Guam made possible a thorough review of tropical cyclones affecting Guam. A special thanks to LCDR James Bell, USN (Ret) whose review of the text eliminated many errors of omission and of commission.

1. INTRODUCTION

Guam, the southernmost island of the Mariana group, lies within the breeding ground for tropical cyclones and thus may be threatened on a year-round basis by the passage of a developing tropical cyclone, and on occasion by a full strength typhoon. Because of their destructive potential, these cyclones are of concern to both the military and civilian communities on the island. This report presents a composite of data concerning tropical cyclone behavior, frequency, and extremes, as well as individual chronicles of those cyclones which have significantly affected Guam. The intent of this report is to serve as a reference for general information purposes. The previous publication, FWC Technical Note (JTWC 75-3) by Holliday (1975) presented this material through 1975; this report adds another five years to this publication.

1.1 TROPICAL CYCLONE CLASSIFICATION

The *typhoon* belongs to a family of atmospheric circulations known as tropical cyclones which originate over the tropical oceans. As opposed to cyclones of the mid-latitudes, tropical cyclones uniquely develop a relatively narrow band of maximum winds encircling a relatively calm center (an eye in intense tropical cyclones). This characteristic which is common to the typhoon is coupled with spiral-like bands of torrential rain which are capable of producing major damage in terms of wind, floods, and sea inundation. *Figure 1* is a satellite view of a typhoon which depicts the markedly clear weather surrounding the cyclone's cloud mass and coil-like cloud banding about the center. *Figure 2* shows a closeup radar presentation revealing the spiraling rainbands beneath the typhoon's high cloud canopy. The ring-like structure of the cloud wall encompassing the eye bears the most intense winds of the typhoon's circulation.

To distinguish intensities of tropical cyclones, the commonly used U.S. classifications of intensities will be used. These classifications categorize tropical cyclones in terms of the sustained wind speed (one minute average at ten meters (approximately 33 feet) elevation over water):

Typhoon ($\geq$*64 kt*), *Tropical Storm* (*34-63 kt*), *Tropical Depression* ($\leq$*34 kt*)

Throughout the text the term *cyclone* is used; in the previous publication (JTWC 75-3), the term *storm* was used interchangably with *cyclone* to describe in general terms that group of tropical cyclones which have attained or are developing maximum sustained winds of at least 34 knots. The use of *knots*, abbreviated kt or kts, is used exclusively throughout this text. A *knot*, meaning a nautical mile per hour, is a measurement of wind speed or speed of movement. It is a unit of measurement similar to miles per hour but slightly larger (to convert knots to miles per hour, multiply by 1.15155). For example, a tropical cyclones reaches typhoon intensity at 64 knots or approximately 74 miles per hour.

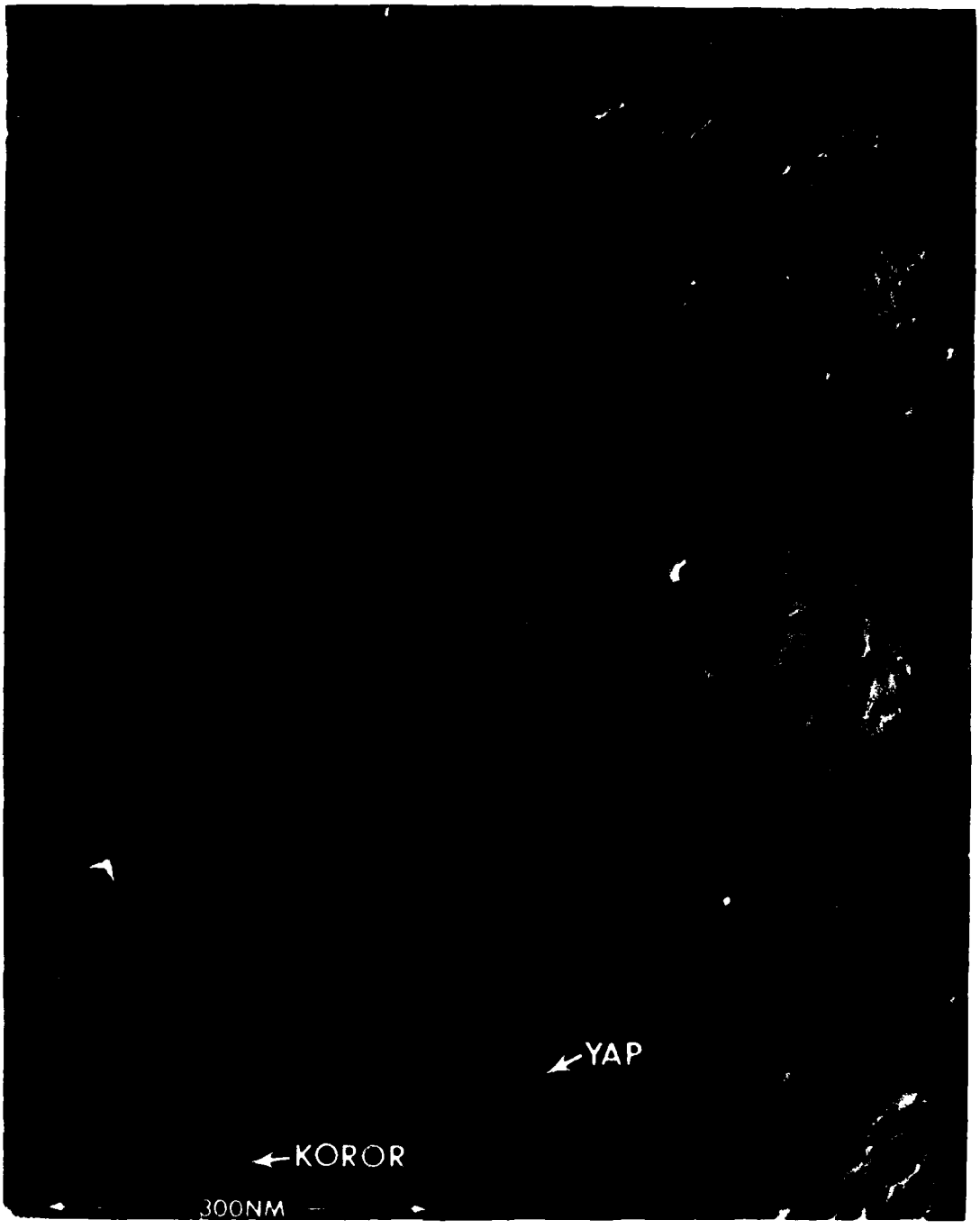

Figure 1 - Satellite view of Super Typhoon Tip shortly before it attained a record minimum sea level pressure of 870 mb. At this time, Tip was located approximately 450 nm west-northwest of Guam with maximum winds of 160 knots. DMSP visual imagery, 0012Z October 1979.

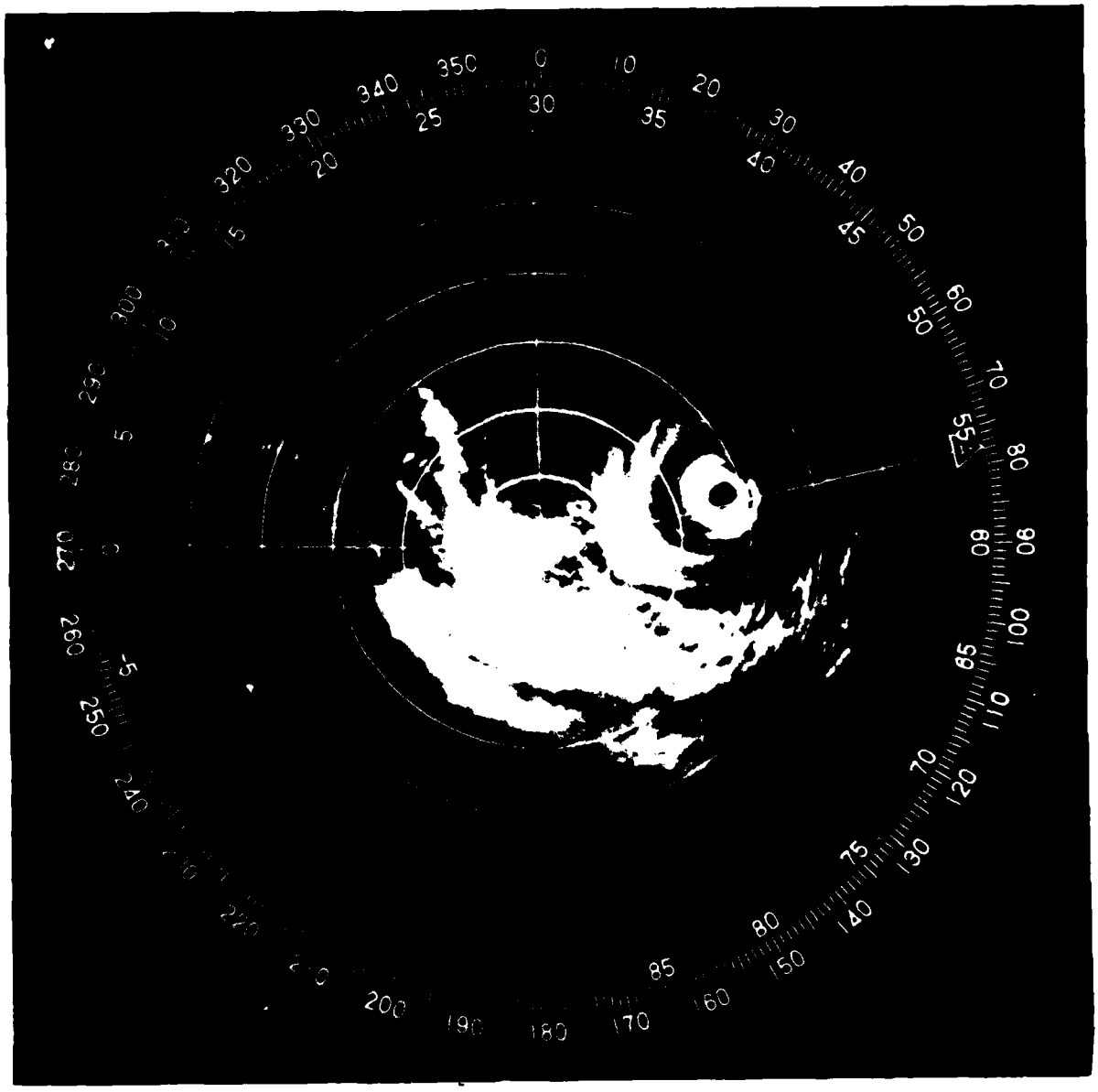

Figure 2 - Typhoon Billie as observed from the Ishigaki Jima radar on 16 July 1973 (0600 GMT) as the typhoon passed through the Ryukyu Islands. Billie's eye is located 80 nm east of the island station. Courtesy Japan Meteorological Agency.

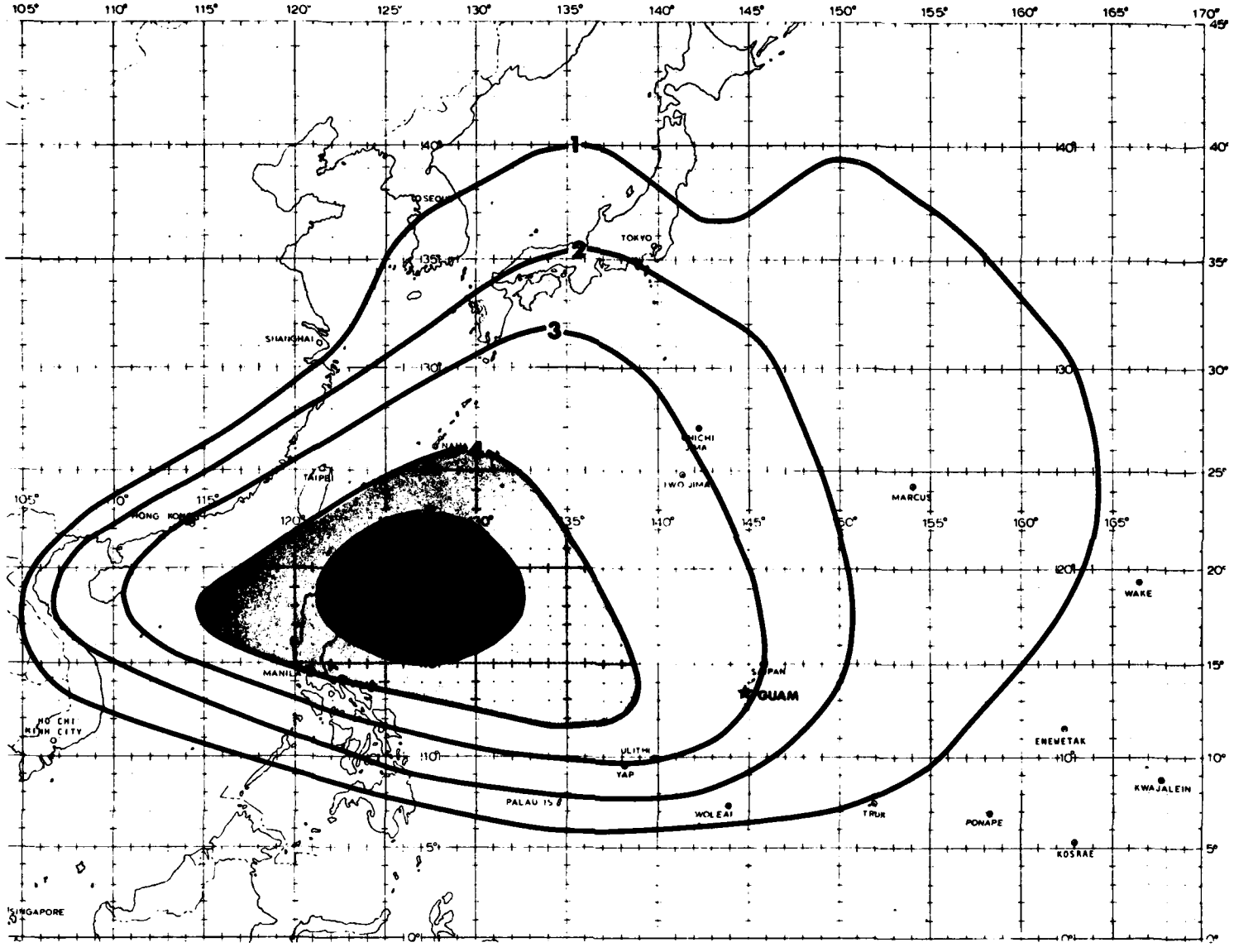

Figure 3 - Mean annual number of tropical storms and typhoons traversing 5 degree latitude/longitude squares. (Based on Crutcher and Quayle, 1974)

1.2 DATA DISCUSSION

Adequate data on tropical cyclone frequency in the western North Pacific, particularly in the vicinity of the Mariana Islands and the Philippine Sea were generally lacking until the late 1940's and the availability of aircraft reconnaissance. First introduced in the region in 1945, aircraft reconnaissance was not conducted on a full-scale, year-round basis until 1948. Thus, the tropical cyclone frequency survey is limited to the period commencing with that year. No attempt has been made to include those cyclones of less than tropical storm intensity (less than 34 knots), since sufficient data on the early stages of tropical cyclone tracks were not available prior to routine satellite observations in 1966. The geographical area under consideration is restricted to within 180 nautical miles (nm) of Guam since, generally speaking, the center of a tropical cyclone must pass within this distance to significantly affect the island with high wind, heavy rainfall, and seas. There were exceptions, however, and these are mentioned where necessary. Also, not all occasions which produced high wind, heavy rainfall, and seas were associated with the approach of a tropical cyclone. However, this discussion will focus only on those events which can be directly associated with tropical cyclone activity. An effort was made by Holliday (JTWC 75-3) to survey all cases of typhoons significantly affecting Guam since 1800 in order to construct a long term picture of frequency and severity. In most of these cases, we must assume the typhoons probably passed within 60 nm of Guam. All typhoons affecting Guam have been listed in the Appendices with a narrative account. For the period since 1946, tropical cyclones have been added in the narrative summary, and a separate listing including specific meteorological data has also been included.

In five cases (all prior to 1963), intensity estimates of tropical cyclones passing near Guam have been reevaluated and reclassified from typhoon to tropical storm strength based on the available data and classification techniques which have been used at the Joint Typhoon Warning Center (JTWC) Guam during the past 15 years. This reclassification was accomplished in the previous publication (JTWC 75-3) and is reemphasized here because of the apparent conflict between the Annual Typhoon Reports for those affected years and the data contained in this publication. The reclassified cyclones are suffixed with an asterisk in Appendix E.

2. FREQUENCY OF OCCURRENCE

Although Guam is located within the breeding ground for tropical cyclones in the western North Pacific Ocean, it is located east and southeast of the main zone of activity (*Figure 3*). An average of 28 tropical storms and typhoons occur annually across the western North Pacific Ocean. Several of these, in various stages of development, threaten Guam each year. During the 33-year period (1948-1980), 94 tropical cyclones developed or tracked within 180 nm of Guam with at least tropical storm strength. This is an average of 2.8 cyclones per year, or 10% of the mean annual count for the western North Pacific. *Table 1* shows that only 33 (35%) were of typhoon strength at their closest point of approach to Guam. This suggests a greater likelihood of a developing typhoon threatening Guam rather than one of full strength.

TABLE 1 - RELATIVE INTENSITY OF TROPICAL CYCLONES (≥34 KTS) WITHIN 180 NM DURING THE PERIOD 1948 - 1980

MAXIMUM SUSTAINED WIND SPEED AT CPA		CASES (PERCENT)	
34 to 49 kts	at tropical storm strength	43 (46%)	61 (65%)
50 to 63 kts		18 (19%)	
64 to 99 kts	at typhoon strength	16 (17%)	33 (35%)
100 kts or more		17 (18%)	

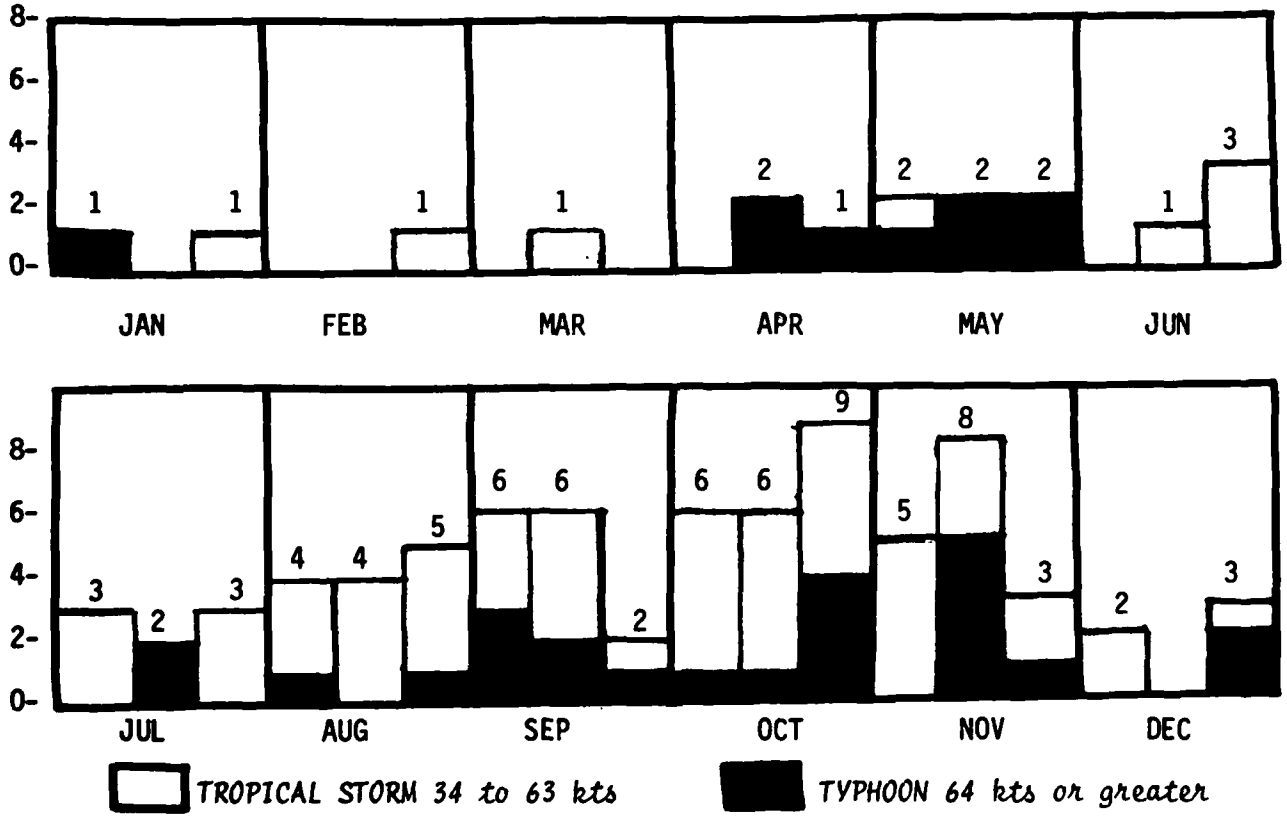

Figure 4 - Monthly occurrence (1948-1980) of tropical storm/typhoon passage within 180 nm of Guam by 10 day intervals (31 day months have the last 11 days included in the last interval).

2.1 MONTHLY FREQUENCY

Figure 4 displays the monthly distribution of tropical cyclones by intensity in the Guam area. Although cyclones have frequented the area during all months of the year, the majority (68%) have occurred during the rainy season months of August-November, with the peak activity in October and November. The commencement of Guam's main tropical cyclone season is linked to the eastward migration of the summer monsoon trough towards the longitude of the Mariana Islands, usually by the end of August (*Figure 5*). This trough provides the favorable environment for the generation of tropical cyclones which may progressively develop into tropical storms and typhoons. In the autumn, the trough is displaced southward and by December becomes absent, as trade winds from the east dominate to near the equator. The trough reaapears at low latitudes (5°N) in the spring as winds from the west occur along the equator (due to the migration of the Southern Hemisphere trough towards the equator - similar to the Northern Hemisphere October and November displacement). This is temporary, and by late May winds from the east once again dominate until the summer southwest monsoon migrates into the area. The presence of this low latitude trough in the eastern Caroline Islands in the late spring accounts for the secondary peak in frequency near Guam from mid-April to May. Because of the trough's low latitude position, tropical cyclones have more time to develop before nearing Guam, which explains the predominance of typhoons affecting Guam during this period.

Tables 2 and *3* give a breakdown of the probability of tropical storm and typhoon center passage within 60 nm increments of Guam based on the records since 1948. It should be noted that available records prior to World War II indicate Guam has been affected by typhoons in the months of February (1864), March (1923) and June (1868, 1873).

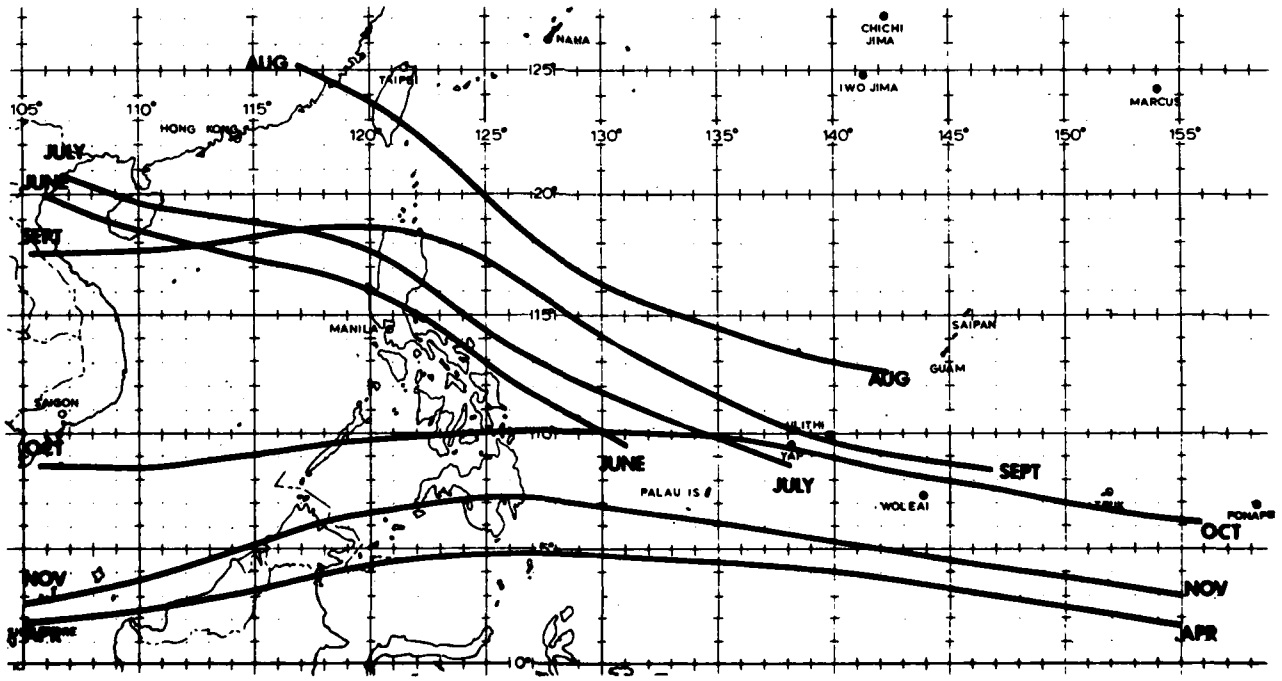

Figure 5 - Mean climatological positions of monsoon trough based on Atkinson (1970), Sadler and Harris (1970).

TABLE 2 - PROBABILITY OF TROPICAL CYCLONE PASSAGE (≥34 KTS) 1948-1980

MONTH	≤180 NM (CASES)	≤120 NM (CASES)	≤60 NM (CASES)
JAN	1 in 16 (2)	1 in 16 (2)	1 in 33 (1)
FEB	1 in 33 (1)	1 in 33 (1)	* (0)
MAR	1 in 33 (1)	1 in 33 (1)	* (0)
APR	1 in 11 (3)	1 in 16 (2)	1 in 33 (1)
MAY	1 in 5 (6)	1 in 11 (3)	1 in 33 (1)
JUN	1 in 8 (4)	1 in 16 (2)	1 in 33 (1)
JUL	1 in 4 (8)	1 in 8 (4)	1 in 33 (1)
AUG	1 in 3 (13)	1 in 4 (8)	1 in 8 (4)
SEP	1 in 2 (14)	1 in 5 (6)	1 in 11 (3)
OCT	1 in 1 (21)	1 in 3 (12)	1 in 4 (8)
NOV	1 in 2 (16)	1 in 3 (13)	1 in 4 (8)
DEC	1 in 7 (5)	1 in 8 (4)	1 in 33 (1)
ANNUAL	2.8 (94)	1.6 (58)	0.9 (29)

TABLE 3 - PROBABILITY OF TYPHOON PASSAGE (≥64 KTS) 1948-1980

MONTH	≤180 NM (CASES)	≤120 NM (CASES)	≤60 NM (CASES)
JAN	1 in 33 (1)	1 in 33 (1)	(0)
FEB	* (0)	* (0)	* (0)
MAR	* (0)	* (0)	* (0)
APR	1 in 11 (3)	1 in 16 (2)	1 in 33 (1)
MAY	1 in 7 (5)	1 in 33 (1)	1 in 33 (1)
JUN	* (0)	* (0)	* (0)
JUL	1 in 16 (2)	1 in 33 (1)	(0)
AUG	1 in 16 (2)	1 in 33 (1)	1 in 33 (1)
SEP	1 in 5 (6)	1 in 16 (2)	1 in 33 (1)
OCT	1 in 5 (6)	1 in 8 (4)	1 in 33 (1)
NOV	1 in 5 (6)	1 in 7 (5)	1 in 8 (4)
DEC	1 in 16 (2)	1 in 16 (2)	(0)
ANNUAL	1.0 (33)	0.6 (19)	0.3 (9)

NOTE: Probability is given as the likelihood of "one" passage every ".." years. (Total occurrences are given in parentheses).

* Available records indicate that Guam has been affected by typhoons in the months of February, March and June prior to 1948.

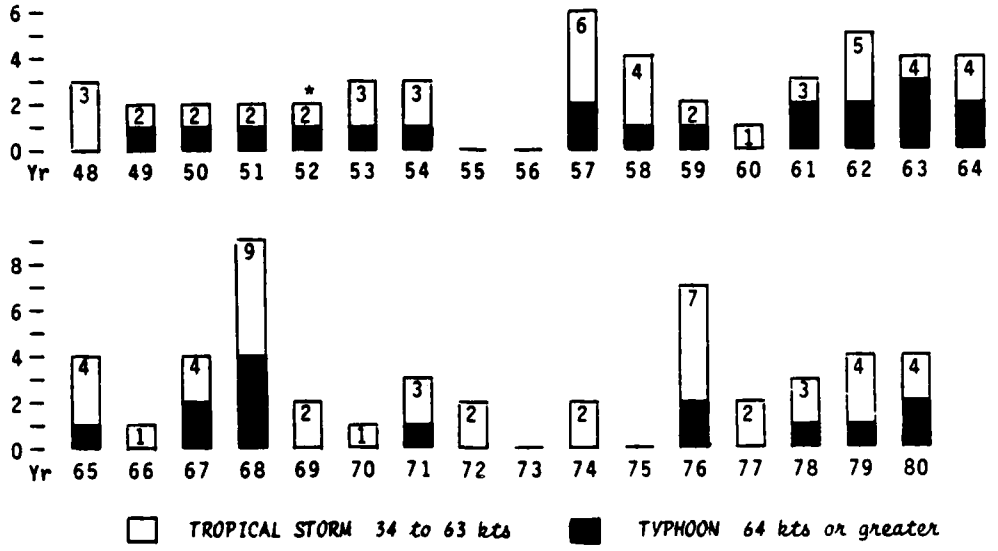

Figure 6 - Yearly frequency of tropical storm/typhoon passage within 180 nm of Guam (1948-1980)

** Typhoon Hester passed south of Guam on 31 Dec 1952 - 1 Jan 1953.*

2.2 ANNUAL FREQUENCY

Although the mean would indicate one typhoon per year, the character of typhoon frequency has been quite irregular since 1954 (*Figure 6*). Approximately 36% (12 years) of the 33-year period has been devoid of typhoons. The most significant absence of activity was in the eight-year period (1969-1975) in which only one typhoon (Amy 1971) passed within 180 nm of Guam. Conversely, nine years have produced 21 typhoons or 64% of the total count for the 33-year period. These were clustered about two year groups, 1961-1964 and 1967-1968, and in the single years, 1957, 1976, 1980. It is interesting to note that during the 15-month period commencing with Gilda in November 1967 and ending with Phyllis in January 1969, 12 tropical cyclones traveled within 120 nm of the island; the period of highest frequency occurred between 22 October and 22 November 1968. In November 1968, four tropical cyclones with at least 34 knot maximum winds and one developing tropical cyclone - Irma, Judy, Kit, Ora and Tropical Depression 31 (later known as Nina) - all passed within 180 nm of Guam.

The aperiodic high tropical cyclone frequency appears to be associated with the abnormal extension of a persistent monsoon trough in the vicinity of the eastern Caroline and Marshall Islands. This extension would provide a fertile ground for tropical cyclone development which would later affect the Mariana Islands. The development of this abnormal extension of the trough may be linked to the presence of above normal sea surface temperatures. Unfortunately, not much data are available to establish a direct link between the abnormal extension of the monsoon trough and a specific change in the ocean environment.

2.3 TYPHOONS PASSING NEAR GUAM

Figure 7 depicts the first points where typhoons (at CPA to Guam) reached tropical storm intensity (≥34 kts). With the exception of eight cases, all typhoons affecting Guam attained tropical storm intensity east of 150E and south of 15N, with the majority of those points in the Truk-Kwajalein area (south of 10N). Typhoons attaining tropical storm intensity in this area have accounted for 64% of all the typhoons which have affected Guam during the 33-year period. Thus the Truk-Kwajalein region is the source of cyclones which present the greatest eventual threat to Guam.

The April typhoons - Georgia (1962) and Olive (1963) were the only typhoons to have threatened Guam from the south. In November 1975, Typhoon June threatened Guam from the south but passed about 220 nm west of Guam, and in May 1980, Typhoon Ellen also threatened Guam from the south but passed 210 nm west of the island. Typhoon Wendy (July 1963) was an anomaly, while intensifying as a tropical storm 50 nm east-northeast of Guam, it reached typhoon strength 24 hours later while on a south-southwestward heading and eventually passed 80 nm south of Guam.

The solid symbols in *Figure 7* identify those typhoons developing sustained winds of 100 knots or greater at the time of their respective closest point of approach. In addition, gusts of at least 120 to 130 knots or nearly twice that of minimum typhoon sustained winds occur with these cyclones (Atkinson, 1974). These gusts are capable of exerting a static wind loading force four times as great as a minimum typhoon because the pressure force increases with the square of the wind speed (Faber and Bell, 1963). Such gusts are capable of inflicting very significant damage on most structures that are not reinforced.

Since the maximum winds of these typhoons are normally confined to a tight ring about the eye (usually not more than 40 to 50 nm in diameter), an essentially direct passage of the center is required to experience their extreme forces. Subsequent to 1946, Karen (1962) and Pamela (1976) have been the only typhoons to cross the island at super typhoon strength (≥130 kts). Typhoons Allyn (1949), Lola (1957) and Olive (1963) could be considered near misses; each made a close approach to Guam with sustained winds at 130 knots or greater. Based on the minimum sea level pressure obtained in the typhoon's center, the strongest typhoons at their closest points of approach to Guam have been: Rita 1978 (899 mb), Lola 1957 (900 mb), Nancy 1961 (905 mb), Allyn 1949 (910 mb), Amy 1971 (910 mb), Karen 1962 (912 mb), Therese 1976 (913 mb), Doris 1950 (922 mb) and Pamela 1976 (930 mb). There is a relationship between the typhoon's minimum sea level pressure and its maximum intensity (Atkinson and Holliday, 1977), generally, typhoons reach the 130-knot super typhoon category between 932 mb and 898 mb. All the above typhoons were in the super typhoon category and Typhoons Allyn, Nancy, Karen and Rita all continued to intensify as they moved westward into the Philippine Sea; in each case the center pressures dropped below 890 mb.

Table 4 lists individual cases of typhoons adversely affecting Guam (causing widespread major structural damage) and provides the distribution of incidences since 1800. Generally speaking, *Table 4* is limited to cases in which the center passed over or just south of the island (≤60 nm). A compilation of

all tropical cyclones appears in the Appendices. The 27 cases noted indicate a probability of one typhoon every seven years adversely affecting the island with a monthly maximum of nine in November and an absence of such activity in January. Evaluating the relative extent of damage, Pamela (May 1976), Karen (November 1962), and the typhoons of November 1940, July 1918 and November 1900 were particularly severe. The typhoons of April 1807, May 1848, September 1855 and October 1891 were also notably destructive. For comparison, Pamela (1976) was the most destructive since the November 1900 typhoon. Looking into the early years of record, the typhoon of November 1693 was probably the most catastrophic.

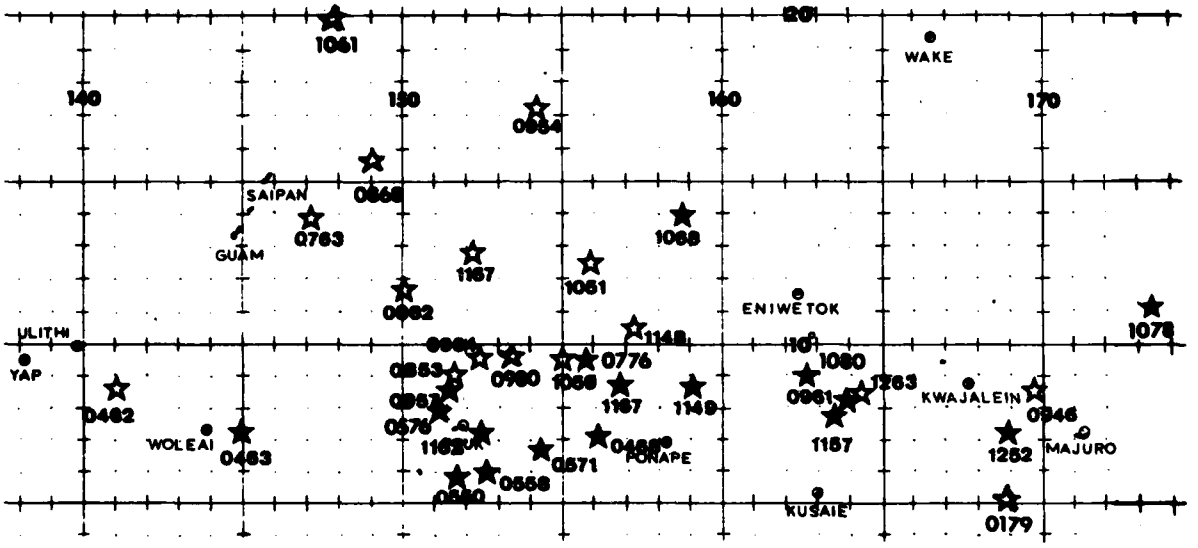

Figure 7 - Initial points of tropical storm intensity (≥ 34 kt) for those typhoons passing within 180 nm of Guam. (Four digit numbers indicate the month and year of occurrence. Solid symbols indicate a typhoon which had sustained winds of 100 kts or more at its closest point of approach)

TABLE 4 - TYPHOONS ADVERSELY AFFECTING GUAM (1800-1980)

1800's		1900's	
APR 1807	FEB 1864	MAY 1900	AUG 1941
MAY 1847	JUN 1868	NOV 1900	SEP 1946
AUG 1848	NOV 1870	OCT 1911	NOV 1949
SEP 1855	AUG 1872	NOV 1913	NOV 1957
APR 1859	DEC 1876	JUL 1918	NOV 1962
NOV 1860	OCT 1891	MAR 1923	APR 1963
NOV 1861		NOV 1940	MAY 1976

3. DIRECTION OF APPROACH AND MOVEMENT

3.1 DIRECTION OF APPROACH

The great majority of the tropical cyclones that passed within 180 nm of Guam have approached from the east-southeast. *Figure 8* displays the frequency of the 58 tropical cyclones which passed within 120 nm of Guam during the 1948-1980 period and their relative movement toward Guam (from 180 nm out to their respective closest point of approach). Of these, 35 (60%) approached from the east-southeast and 46 (79%) approached from the southeast quadrant. Westward movers, i.e. those approaching Guam from the northeast and southeast quadrants, account for all but five of the tropical cyclones which passed within 120 nm of Guam; of these, four approached from the southwest quadrant. Olive (April 1963) was the only tropical cyclone during the 33-year period which originated south of Guam and adversely affected the island. As indicated in *Figure 8*, three other tropical cyclones developed with 120 nm of Guam but did not approach closer to the island before moving out of the area.

Not all approaching tropical cyclones have been as well behaved as *Figure 8* may suggest. Many tropical cyclones have displayed loops or have stalled near their points of closest approach, or have performed major deviations in track, making it difficult to assume a uniformity to their motion of approach. *Figures 9* and *10* display the tracks of some of these cyclones, with Lola (October 1963) being one of the most erratic movers. Lola's center passed over Guam while a tropical depression, only to return as a tropical storm, skirting just west of the island while tracking northward. Several other unusual cyclones were Violet (October 1961), Wendy (July 1963) and Carmen (August 1978); each exhibited a southwestward track while they were to the west or northwest of Guam. The months of October and November offer an interesting contrast on tropical cyclone tracks near Guam. Of the 21 cyclones which have passed within 180 nm of Guam in October, 11 exhibited changes of 45 degrees or more in heading inside the 180 nm radius of Guam. In contrast to the erratic behavior of October, the November cyclones have displayed a steady movement when near Guam, with only one of 18 tropical cyclones deviating by more than 20 degrees in heading within the 180 nm radius.

3.2 SPEED OF MOVEMENT

The majority of the tropical cyclones (75%) passing within 180 nm of Guam had, at their points of closest approach, a mean speed of movement near 11.7 knots. Some seasonal variability is evident as shown in *Figure 11* In general, the movement and speed of a tropical cyclone is influenced by its proximity to the prevailing steering current, primarily the subtropical ridge. This ridge is a semi-permanent feature at the mid-latitudes throughout the year; however, the ridge is displaced towards the equator in the Northern Hemisphere winter and towards the pole in the Northern Hemisphere summer. The late fall and winter months (November-February) show the evidence of the equatorward displacement of the subtropical ridge by

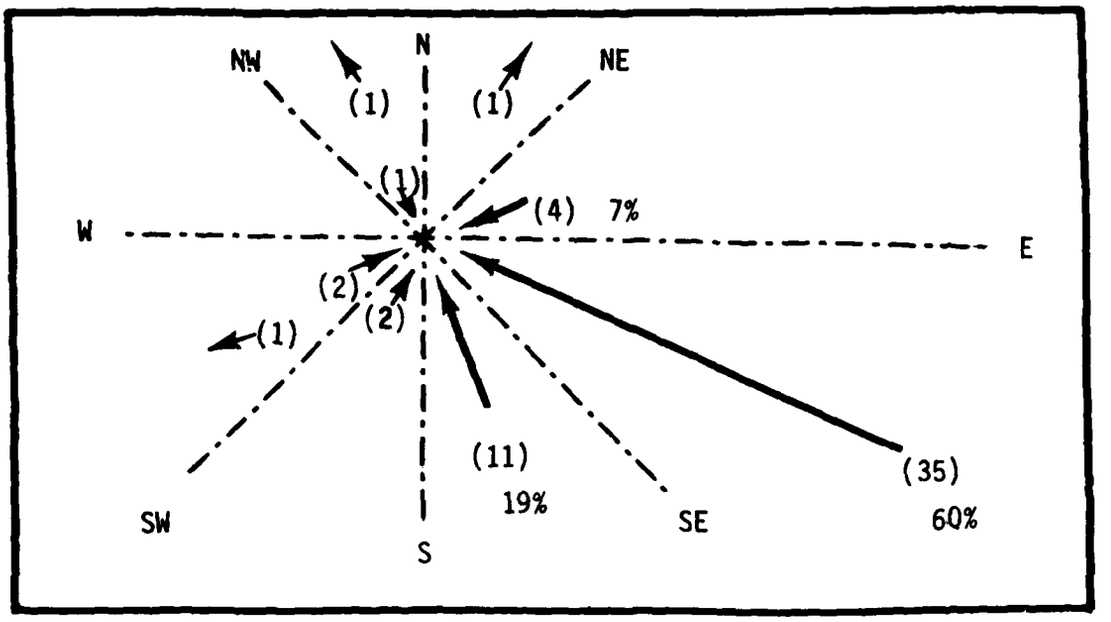

Figure 8 - Direction of approach of tropical cyclones (>34 knots) passing within 120 nm of Guam (1948-1980). Length of each line represents the number of occasions in which cyclones approached from each octant of the compass as viewed from Guam.

TABLE 5 - PASSAGE NORTH OR SOUTH OF GUAM (BY MONTH) FOR THOSE TROPICAL CYCLONES (≥ 35 KTS) APPROACHING FROM THE EAST AND PASSING WITHIN 120 NM OF GUAM (1948-1980)

Closest Point of Approach*	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
to 120 nm NORTH	0	0	0	1	1	0	1	5	0	6	7	1	22
to 120 nm SOUTH	2	1	0	0	2	0	2	2	5	6	6	2	28

* point of reference - Agana (13.4N 144.7E)

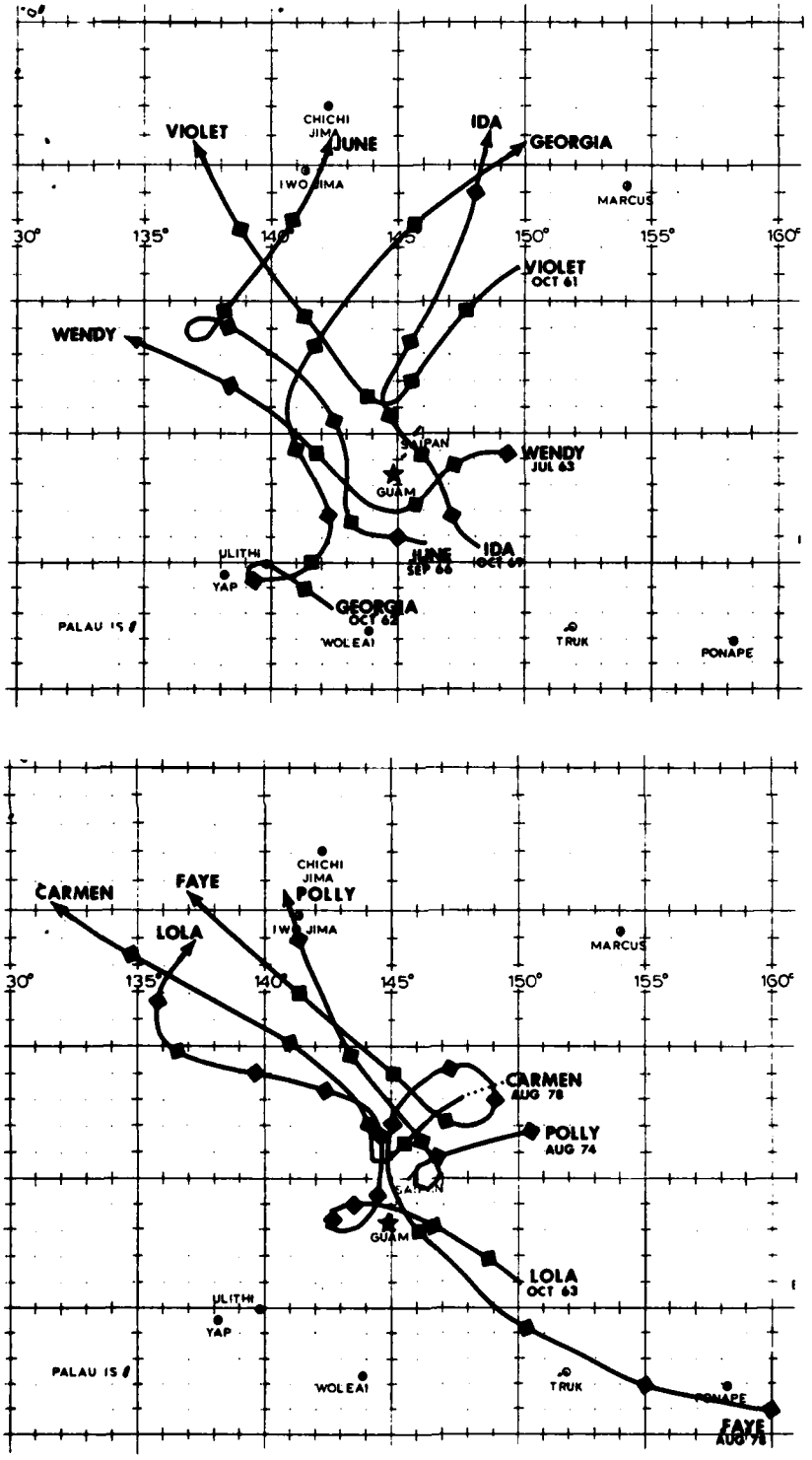

Figure 9 - Tracks of looping or stalling tropical cyclones in vicinity of Guam ■ - position of tropical cyclone at 0000Z (1000 Guam) each day.

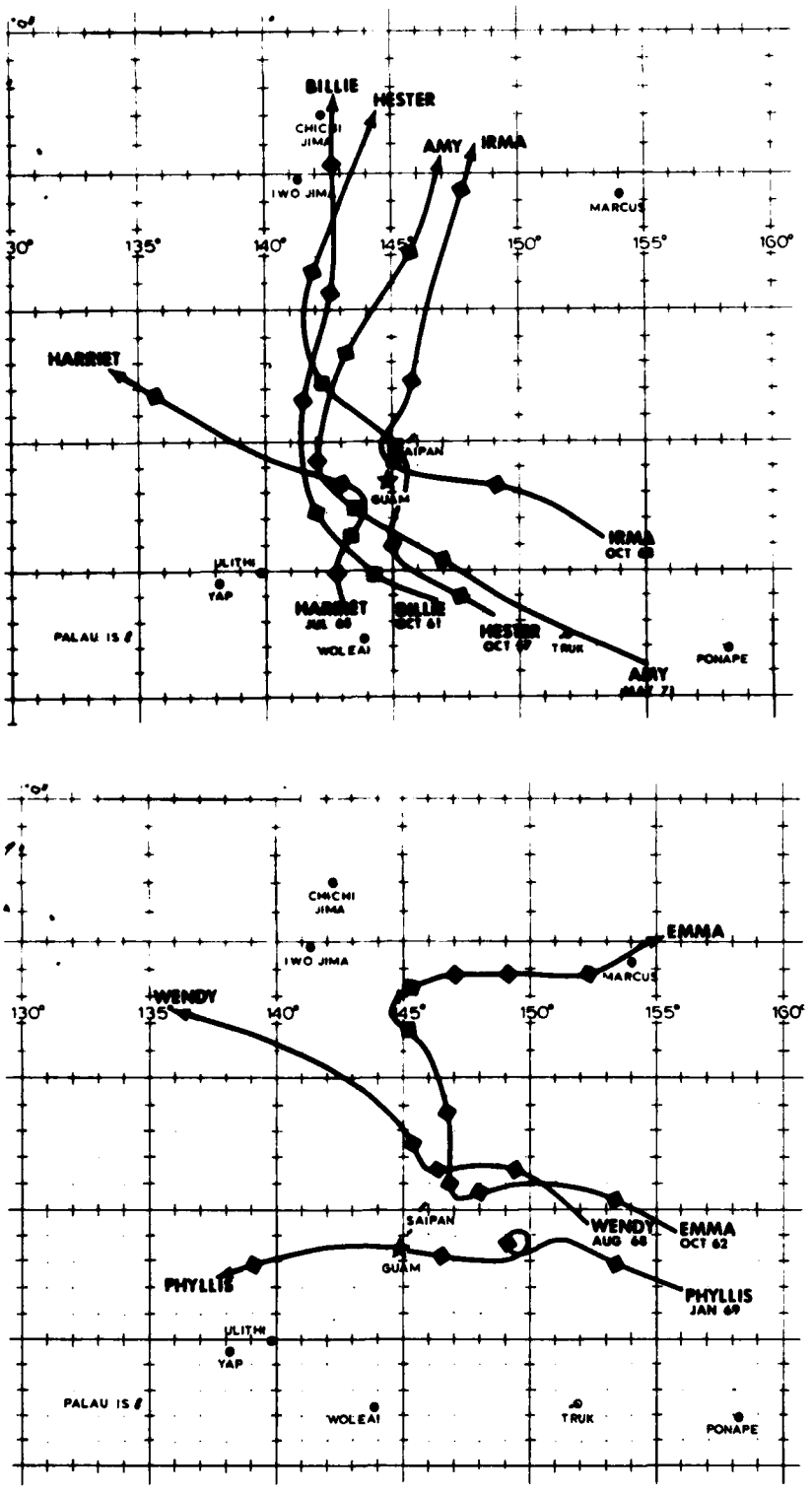

Figure 10 - Major changes in the direction of tropical cyclone movement in vicinity of Guam.

■ *- position of tropical cyclone at 00002 (1000 Guam) each day.*

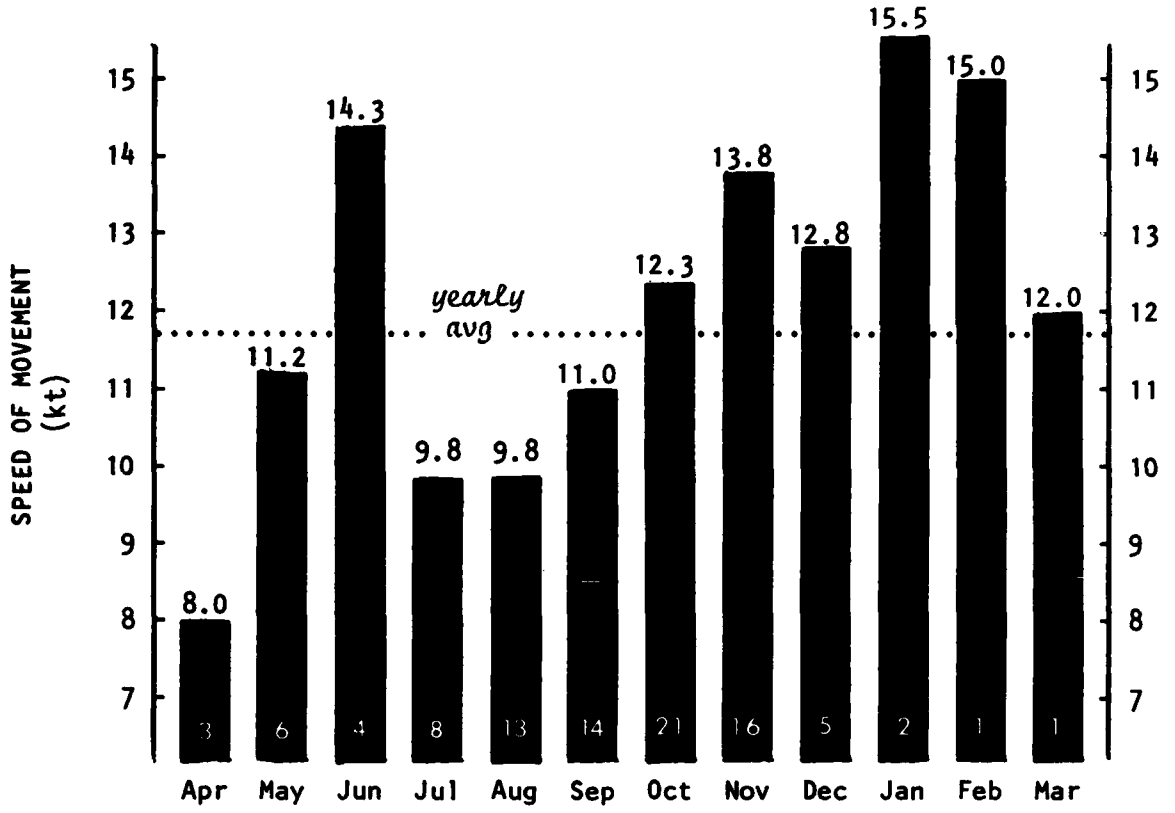

Figure 11 - Monthly average speed of movement for tropical cyclones at their closest points of approach to Guam (1948-1980)

the higher than average speeds of tropical cyclones at Guam's latitude. On the other hand, the summer months (July and August) show evidence of the poleward displacement of the subtropical ridge through the lower than average speeds of the tropical cyclones near Guam. The apparent short-term trend from April to June (of increasing speeds of movement) cannot be as easily explained by the seasonal location of the subtropical ridge. During this period, the southern periphery of the ridge gives way to an early development of the near-equatorial trough, which then collapses in late May or early June to the Philippine Sea, west of Guam. Thus by June, tropical cyclones tend to move more rapidly near Guam because of a brief return to a winter-like trade wind environment over the region. The spring months of March and April have had relatively few tropical cyclones, although April, with three cyclones, has the lowest average speed with 8.0 knots. Two of the fastest moving tropical cyclones were Typhoon Hester (December 1952) which passed 120 nm south of Guam at 22 knots and Tropical Storm Faye (October 1971) which passed near Saipan at 27 knots. Within 180 nm of Guam, 11 cyclones in all have been observed to travel at speeds of 19 knots or greater. By contrast, a slightly higher number (15) have displayed unusually slow speeds ($\leq$7 knots, including some in loops). One of the slowest moving tropical cyclones passing near Guam was Alice (October 1953); the center of this developing tropical storm passed over the northern portion of Guam at five knots, resulting in a 24-hour rainfall of 18.33 inches.

3.3 ACCELERATION

The majority of the tropical cyclones approaching Guam have moved at a rather uniform rate; however two cyclones, Phyllis (January 1969) and Karen (November 1962), exhibited marked acceleration. Phyllis slowed to a stall as a weakening typhoon 270 nm northeast of Guam, then proceeded on a small looping track for 18 hours before accelerating towards Guam and reached a speed of 20 knots before passing over the island. Fortunately, Phyllis had weakened to a minimal tropical storm (35 knots) before reaching Guam. Karen, on the other hand, was slowly drifting northward at five knots as a severe typhoon (120 knots) while 480 nm east-northeast of Guam. Karen then abruptly shifted track toward the west-northwest and increased its rate of speed (to 17 knots) and struck Guam in just 36 hours.

During its period of development, Tropical Storm Tip (October 1979) meandered for several days in the Truk district (about 600 nm southeast of Guam). After describing several looping patterns near Truk, Tip accelerated to 20 knots. Then, just eight hours prior to closest point of approach, Tip slowed to less than 10 knots and passed south of Guam. Fortunately for Guam, just after passing the island Tip began to rapidly intensify into a super typhoon and reached a maximum intensity of 165 knots 465 nm west-northwest of the island.

4. METEOROLOGICAL ASPECTS

4.1 GALE CONDITIONS

Since 1946, tropical cyclones passing Guam have resulted in at least 67 occurrences of gale force winds ($\geq$34 knots), with a duration of one hour or more. Distances of center passage have varied, but the majority (87%) passed within 180 nm of the island. However, tropical cyclones passing as far as 450 to 600 nm have, on occasion, given Guam gusts of gale force. A geographical distribution of the points of closest approach along the tracks of cyclones producing gale force winds, is shown in *Figure 12*. A greater occurrence (73%) of these gales is shown for those cyclones which passed over, or just south of Guam. From the data recorded on Guam, those cyclones which passed south of the island have brought strong gusts from distances greater than those which passed north of Guam. This is not unusual; the normal distribution of winds about a tropical cyclone ordinarily extend much further to the right of the direction of motion. Since the overwhelming majority of tropical cyclones passing Guam have been westward movers, it stands to reason that this relationship would hold true from the recorded data. However, wind distribution about individual tropical cyclones can be quite variable. For example, Typhoon Faye (August 1957) and Super Typhoon Rita (October 1978) passed 135 nm and 82 nm south of Guam with maximum winds of 105 knots and 150 knots respectively. If either cyclone had been "typical" their relative effects on Guam would have been different from the historical record. Faye brought a peak gust of 35 knots to Guam while Rita did produce a maximum gust of 72 knots. However, Rita was so compact that at the Naval Air Station, 12 miles north of the location recording the 72-knot gust, the maximum wind recorded was just 35 knots!

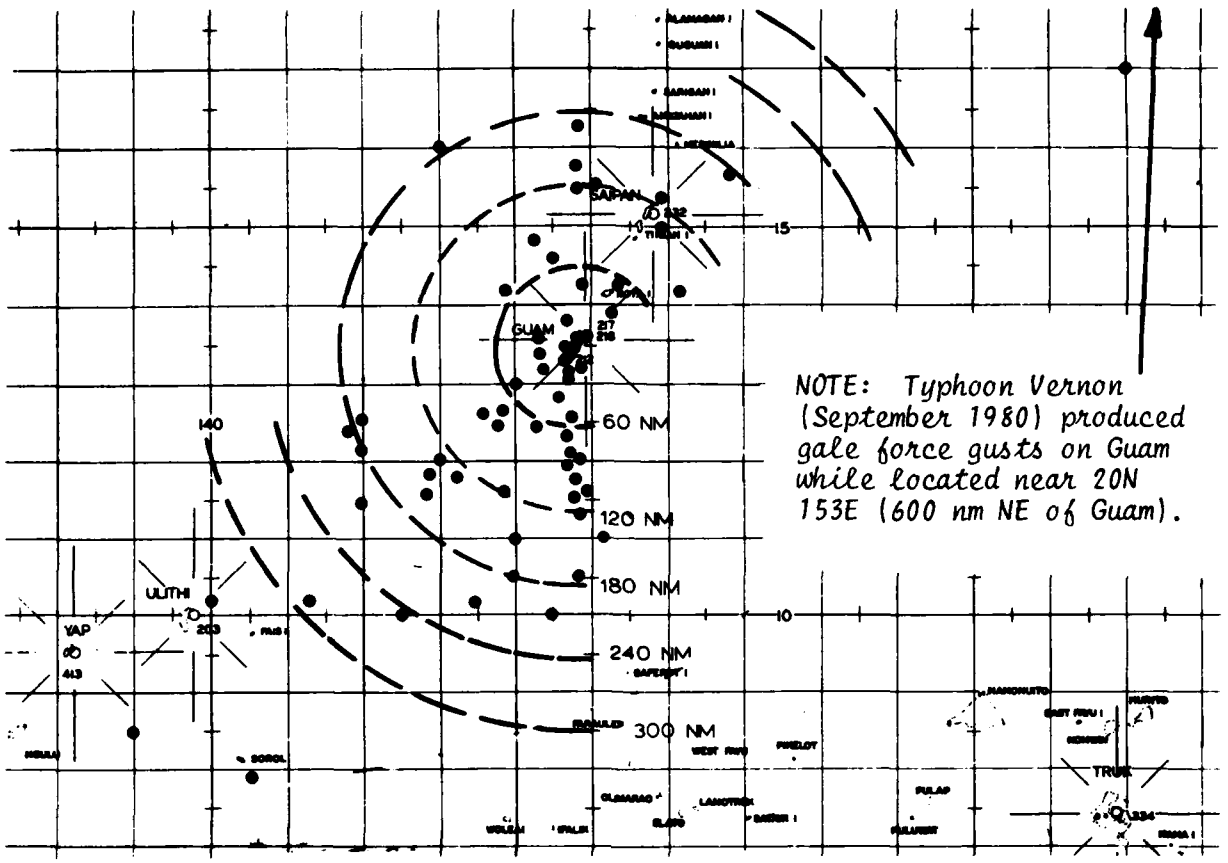

Figure 12 - Closest points of approach of tropical cyclones causing gale force gusts for one hour or more on Guam.

By contrast, Typhoon Opal (December 1964) tracked 450 nm to the southwest of Guam and brought a gust of 43 knots to the island. This was the result of an unusually tight gradient of pressure between the typhoon and a zone of high pressure north of Guam. Tropical Storm Mary (August 1974) presented an unusual distribution of strong winds in the southern portion of the circulation, brought about by the enhancement of a strong southwest monsoon across the entire expanse of the Philippine Sea. Although Mary's center was located some 450 nm northeast of Guam, a band of heavy weather produced gusts of 57 knots on the island. Gale or near gale force gusts occurred for a period of 67 hours - a record for any cyclone affecting the island since 1945. This compares with an average duration of 14 hours for all 67 cases. Typhoons which have produced gale, or near gale, conditions for a period of 40 hours or more include: Olive (April 1963), Gilda (November 1967), Jean (April 1968), Amy (May 1971), Mary (August 1974), and Pamela (May 1976).

Tropical cyclones causing strong gusts of 50 knots or greater have been experienced on 33 occasions since 1946. With the exception of Mary (December 1977), June (November 1975), Mary (August 1974) and Lorna (September 1954), all points of closest approach occurred within 120 nm of Agana.

4.2 MAXIMUM WINDS

The strongest wind gust ever recorded in a typhoon was 166 knots near the eye of Typhoon Cora (September 1966), at the Japanese Meteorological Station on Miyako Jima (elevation 132 feet). Wind gusts undoubtedly have been higher, but during the rare occurrence of a well developed typhoon passing near a meteorological station, weather conditions become so extreme that the anemometer (wind instrument) often fails or is blown away. *Table 6* lists some of the wind extremes measured on Guam, with the casuality toll on wind instruments rather evident.

TABLE 6 - SOME WIND EXTREMES MEASURED ON GUAM

	TYPHOON	PEAK GUSTS (KNOTS)	LOCATION	ELEVATION (FT)
1.	Pamela (May 1976)	138	Taguac (NWS)	365
2.	Karen (November 1962)	125*	Nimitz Hill (NOCC)	634
3.	(March 1923)	122*	Sumay (MCAS)	25
4.	(November 1940)	110*	Agana (Fort Apugan)	182
5.	(August 1941)	108	Agana (Fort Apugan)	182
6.	Olive (April 1963)	87	Nimitz Hill (NOCC)	634
7.	Lola (November 1957)	84*	Naval Air Station	255
8.	(September 1946)	82	Naval Air Station	255
9.	Betty (November 1980)	79	Naval Air Station	255
10.	Ora (November 1968)	77	Andersen AFB	644
11.	Kim (November 1977)	77	Nimitz Hill (NOCC)	634

* Anemometer failed

With the exception of the November 1900 typhoon, Karen (November 1962) was the most intense (greatest maximum wind speed) typhoon to strike the island this century. With a central pressure of approximately 912 mb near Guam, the pressure-wind relationship of Atkinson and Holliday (1977) would estimate that sustained winds of 130 knots, with gusts to 160 knots, were possible near Guam. Due to topographical effects the wind intensity over land can be distorted, producing gusts greater than those over water. During the period that Karen moved over Guam, wind gusts up to 180 knots were estimated at various locations on the island.

Typhoon Pamela (May 1976), with a central pressure of approximately 930 mb, was estimated to support maximum winds of 120 knots, with gusts to 145 knots, when it struck Guam. However, due to Pamela's slow rate of movement (7 knots) it became the most destructive typhoon of the century for Guam because of the prolonged period of 50-knot or greater winds (30 hours).

A notable characteristic of the wind speeds accompanying both Karen and Pamela was their non-steady nature. This gustiness - peaking, then dropping to a relative lull - is seen to vary as much as 80 knots in a matter of minutes (*Figure 13*). This pulsating and gusty nature of the wind results in an uneven, intermittent pressure and wrenching effect. It is also significant

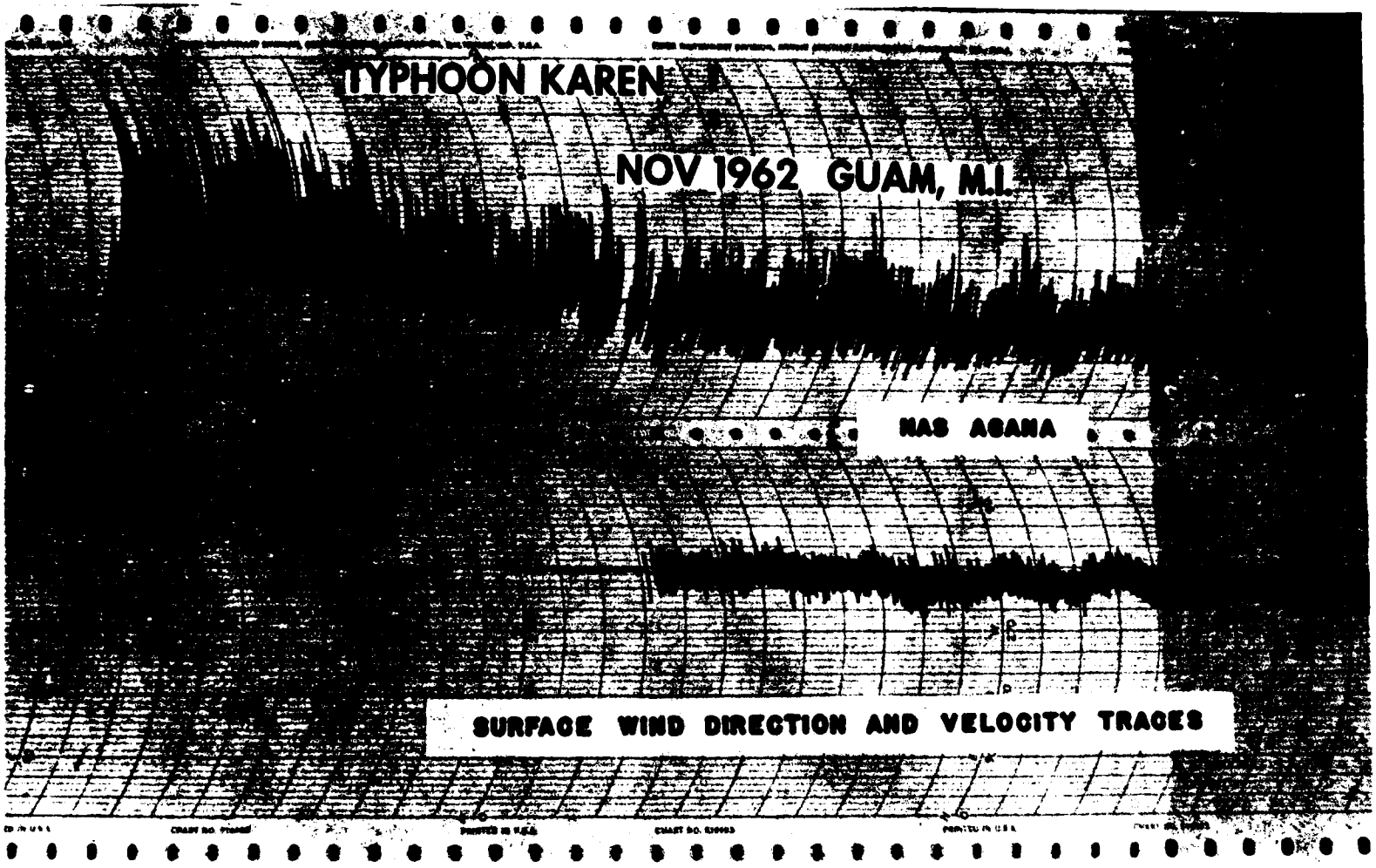

Figure 13 - Surface wind direction and velocity traces for Super Typhoon Karen, Nov 1962

that the wind causes not only a pressure on the windward side but it also causes a suction effect on the leeward side of structures. During each of these typhoons, this fluctuation of wind intensity resulted in extremely large pressure differences (60 to 70 pounds per square foot) in less than a minute during the passage of the eye. Few structures that were not reinforced resisted such blasts.

4.3 ATMOSPHERIC PRESSURE

Table 7 shows the minimum sea level pressures recorded on Guam, for values less than 980.0 mb, based on available records since 1900. Both the November 1900 typhoon and Karen (November 1962) had unusually low pressures. However, neither observation was made directly in the eye of the typhoon (as Pamela (May 1976) was observed) as both centers passed south of the meteorological stations on Guam. Thus, the actual lowest pressure was not measured as the typhoons passed Guam. In the case of Karen, the central pressure was estimated near 912 mb based on interpolation of aircraft reconnaissance measurements shortly before and after landfall. Although such a low pressure is relatively infrequent for typhoons, it is still considerably above the lowest sea level pressure on record. That value was 870 mb, obtained by aircraft reconnaissance in Super Typhoon Tip (October 1979) while located 465 nm west-northwest of Guam (16.7N 137.8E).

TABLE 7 - SOME MINIMUM SEA LEVEL PRESSURE MEASUREMENTS ON GUAM

	TYPHOON	DATE	PRESSURE (mb)	LOCATION	REMARKS
1.	Not named	NOV 1900	926.5	Agana	
2.	Pamela	MAY 1976	931.7	Naval Air Station	In eye
3.	Karen	NOV 1962	931.9	Naval Air Station	Central pressure est. at 912 mb
4.	Not named	JUL 1918	954.6	Agana (Agricultural Experimental Station)	In eye
5.	Not named	NOV 1940	955.6	Agana (Fort Apugan)	
6.	Not named	AUG 1941	969.9	Agana (Fort Apugan)	
7.	Allyn	NOV 1949	971.9	North Field	
8.	Not named	SEP 1946	972.4	Harmon Field	
9.	Not named	DEC 1876	974.9	Agana	
10.	Olive	APR 1963	976.5	Nimitz Hill (FWC)	
11.	Lola	NOV 1957	978.1	Naval Air Station	
12.	Kim	NOV 1977	978.9	Andersen AFB	

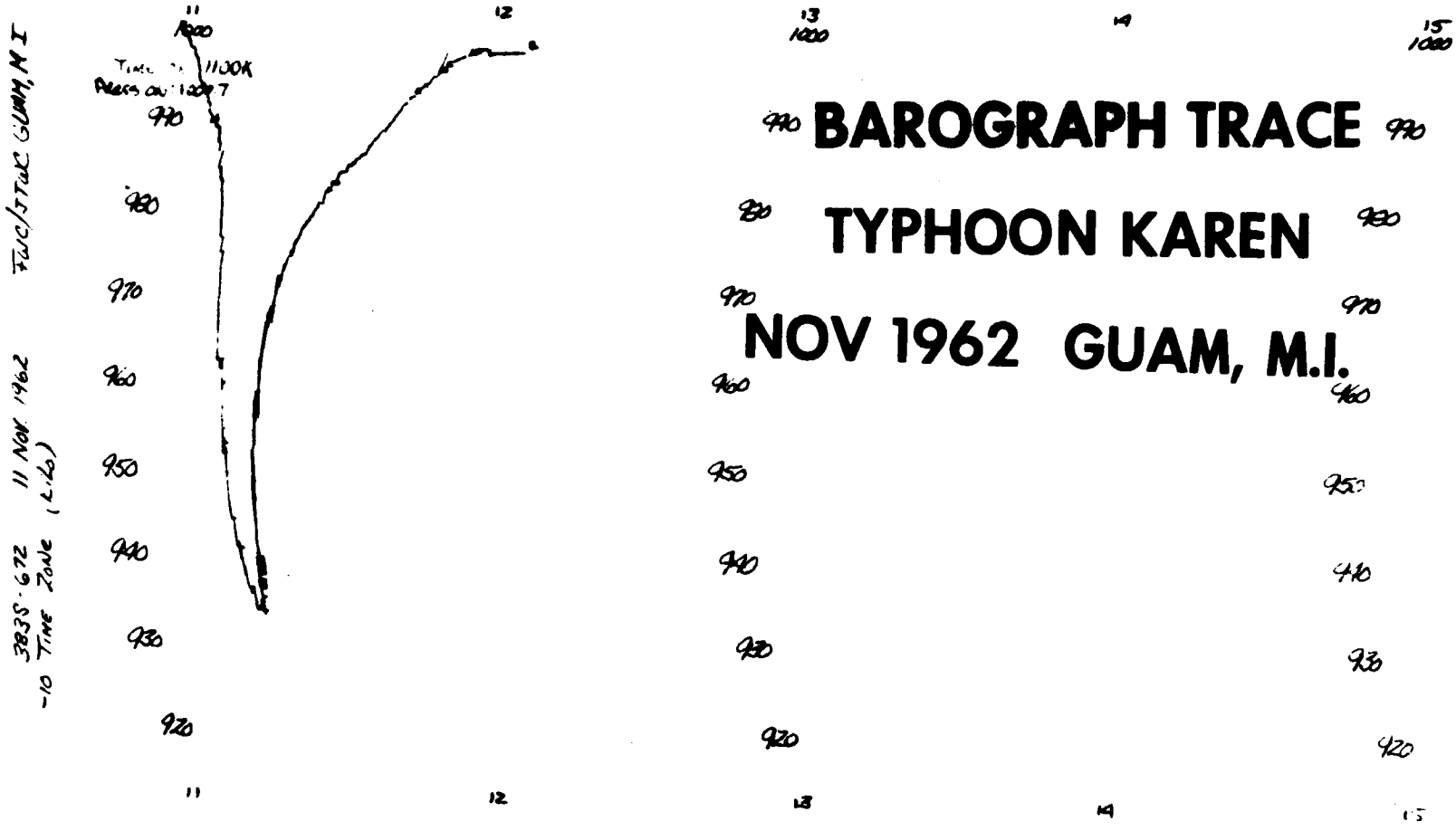

Figure 14 - Barograph trace for Super Typhoon Karen, Nov 1962, taken at FWC/JTWC, Nimitz Hill

Figure 14 is the Naval Oceanography Command Center (then Fleet Weather Central) Guam barograph trace during Typhoon Karen. The center passed 10 nm south, and based on the Naval Air Station barometeric pressure reading (931.9 mb) at this point of closest approach, an extreme pressure gradient of 27 mb per nautical mile existed over the southern half of the island. Due to Karen's above normal rate of motion (17 knots) the pressure fell at a rapid rate. From a reading of 1000 mb at 1100 local the pressure fell nearly 66 mb in 11½ hours, a rate of 5.7 mb per hour. Between 2130 local and 2230 local the change was 29.0 mb per hour - a drop rarely recorded at a meteorological station. This sudden drop in pressure and the extreme gustiness of the wind resulted in an explosive action on reinforced concrete structures. "Window panes and/or entire louvered casements were forced outward, including doors and/or frames, particularly the French doors in living quarters" (FWC/JTWC, 1962).

4.4 RAINFALL

The amount of rainfall associated with the passage of a tropical cyclone can be highly variable, and is dependent on several factors including the rate of forward motion of the cyclone and the position of the rain gauge with respect to the cyclone's track. However, the highest rainfall measurements in tropical cyclones are usually recorded in mountainous regions. This is a result of orographic lifting, which increases the rate of ascent of the moisture laden air and augments the total rainfall. It should be noted that the actual measurement of rainfall under typhoon conditions is difficult, as significant amounts of rain blow out of the rain gauge, with a loss of as much as 50% possible (Dunn and Miller, 1960). Another factor inhibiting accurate measurements is the sharp angle of incidence of driving rain to the opening of the rain gauge. During the passage of Pamela (May 1976), an observer reported rain being driven horizontally, making the record rainfall totals from Pamela even more conservative.

Figure 15 shows the frequency distribution of the maximum 24-hour rainfall brought by each of the tropical cyclones passing within 180 nm of Guam. The bulk of the cases (77%) indicate that amounts up to four inches are fairly common during center passage with the median 24 hour rainfall near 2.5 inches. As an example of some of the contrasting characteristics from cyclone to cyclone, Typhoon Jean (April 1968), while passing over Saipan, produced only 0.33 inches in 24 hours on Guam. In contrast, developing Tropical Storm Carla (May 1974), on a similar track and also passing over Saipan gave Guam 4.30 inches in 24 hours. *Table 8* lists those tropical cyclones which caused above normal rainfall ($\geq$ 6 inches) since 1946. For purposes of comparison, six inches is almost half the mean total of 13.13 inches for September, the rainiest month of the year (based on available data from 1945 to 1979). With the exception of Mary (August 1974) and Vernon (September 1980) all the cyclones passed within 120 nm of Agana.

In all cases except Karen (November 1962), Irma (February 1953) and Vernon (September 1980), the rate of forward motion was near or below the average rate of 11.7 knots, allowing prolonged exposure to the cyclone's heavy rainbands. It is interesting to note that over half of these cases (9) of heavy rainfall were produced by tropical cyclones of depression or storm strength rather than those of typhoon strength.

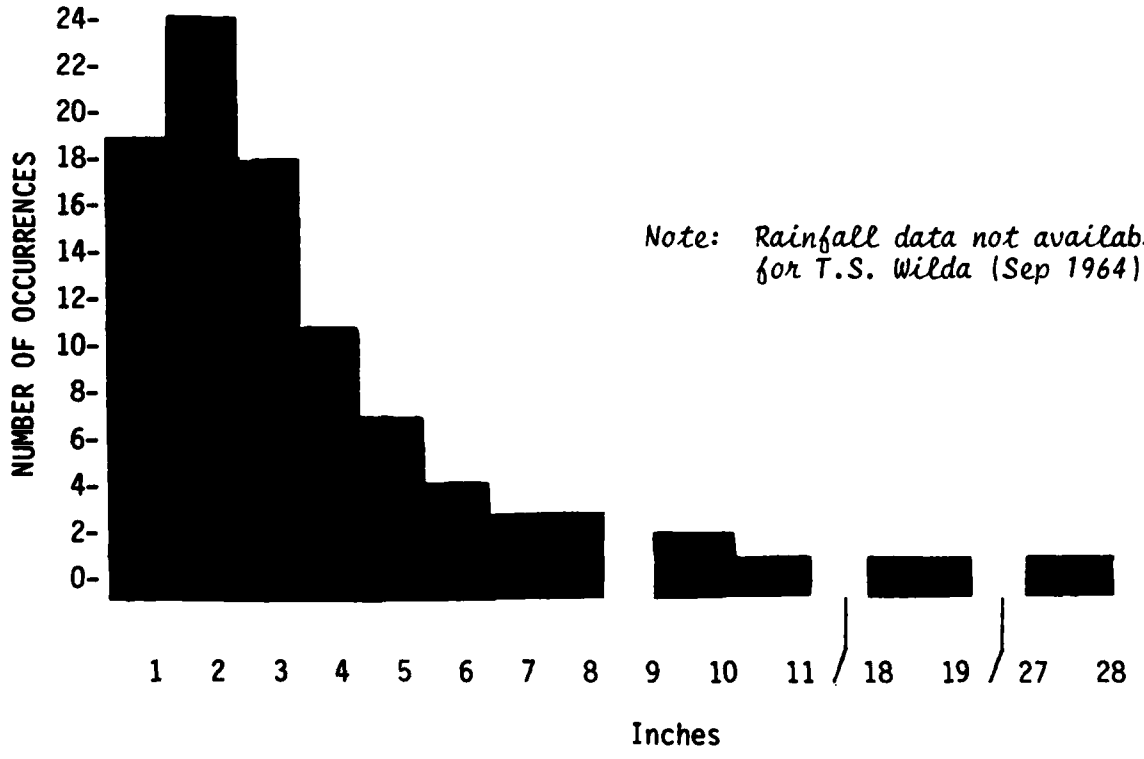

Figure 15 - Frequency distribution of the maximum 24 hour rainfall occurring on Guam with the passage of tropical cyclones (≤180 nm) 1948-1980

TABLE 8 - MAXIMUM 24-HOUR RAINFALL TOTALS ON GUAM* (1946-1980)

TROPICAL CYCLONE	DATE	AMOUNT (INCHES)	LOCATION	CPA
TY. PAMELA	MAY 1976	27.00	Taguac	- 0
T.S. ALICE	OCT 1953	18.33	Andersen AFB	N 15
T.S. TIP	OCT 1979	10.14	Taguac	S 40
TY. AMY	MAY 1971	9.92	Taguac	SSW 90
T.S. IDA	OCT 1969	9.38	Taguac	NNE 90
T.S. IRMA	FEB 1953	7.88	Andersen AFB	S 90
T.D. POLLY	AUG 1971	7.81	Taguac	NNE 85
T.S. VIRGINIA	SEP 1965	7.48	Taguac	NE 130
T.D. MARY	AUG 1974	7.36	Taguac	NNE 485
TY. NINA	AUG 1953	7.07	Andersen AFB	N 15
T.D. BABE	APR 1974	6.37	Taguac	E 40
T.S. ORCHID	SEP 1980	6.34	Taguac	N 75
TY. KAREN**	NOV 1962	6.32	Taguac	S 10
TY. SUSAN	DEC 1963	6.09	Taguac	N 75
TY. VERNON	SEP 1980	6.09	Taguac	NE 600

* (1) The second highest recorded rainfall occurred on 1 October 1924, approximately 24.5 inches in 24 hours (Agana Agricultural Station)
(2) During a typhoon on 6 July 1918, 10.50 inches was recorded in 24 hours
(3) An unnumbered tropical depression produced 10.89 inches in 24 hours on 26 February 1980 (Naval Oceanography Command Center)

** Power to the rain gauge failed during Karen (this observation was taken the day after passage, which leads to the possibility that significantly higher amounts may have occurred the previous day near CPA).

The highest total of 27.00 inches was produced by Pamela (May 1976), while the center moved over the middle of the island at six to seven knots. Other significant rain producers have been the October 1924 typhoon with 24.50 inches and Typhoon Alice (October 1953) with 18.33 inches in 24 hours. By comparison, this is still well short of the record 24 hour measurement for an island of relatively low terrain; a downpour totaling 42.40 inches was recorded on Okinawa in September 1956 during Typhoon Emma's passage (Jordan and Shiroma, 1959). Typhoons Pamela (May 1976), Alice (October 1953) and the October 1924 typhoon resulted in considerable damage, as extensive runoff due to prolonged rains caused rivers to overflow their banks, washed out bridges and inundated the adjacent low lying areas. Excessive rainfall accumulation due to poor drainage in other areas has also caused significant flooding.

The information on rainfall amounts accumulating in a period of an hour is quite limited as records of hourly readings are only available since 1957. *Table 9* lists those tropical cyclones which caused one-hour rainfall totals of 1.5 inches or greater, with Virginia (September 1965) heading the list at 3.43 inches. It should be noted that accumulations of up to one inch per hour are occasionally recorded in heavy rainshowers which are not associated with

tropical cyclone activity. Records for one-hour rainfall extremes are somewhat sketchy for cases of tropical cyclones affecting relatively flat areas. However, Dunn and Miller (1964) cite a six-inch accumulation for a period of 75 minutes at Hialeah, Florida in connection with the passage of a hurricane on 12 October 1947.

TABLE 9 - SOME MAXIMUM RAINFALLS (≥1.5 inches per hour) 1957-1980*

TROPICAL CYCLONE	DATE	CPA	1 HR RAINFALL (INCHES)
T.S. VIRGINIA	13 Sep 1965	NE 130	3.43
T.D. IVY	19 Oct 1977	E 110	3.21
T.D. JOAN	25 Aug 1959	N 130	2.82
T.S. EMMA	02 Oct 1962	NNE 170	2.13
TY. AMY	12 May 1971	SSW 90	1.83
TY. WENDY	11 JUL 1963	SW 80	1.79
T.S. IDA	16 Oct 1969	NNE 90	1.73
T.S. TIP	10 Oct 1979	S 40	1.61
T.S. ORCHID	09 Sep 1980	N 75	1.54

TYPHOON PAMELA (May 1976) is estimated to have rates which were greater than 1.50 inches per hour, however, due to instrument failure no data are available.

* All measurements were recorded at the National Weather Service Office, Taguac.

4.6 STORM SURGE

Inundation of low-lying coastal areas by the sea has occurred during the passage of severe cyclones near Guam. An inspection of the narrative accounts since 1946 would indicate that significant inundation should be expected in low-lying coastal areas with the passage of the center of a tropical cyclone of typhoon force within 60 nm of Guam. However, specific information on Guam storm surges is quite sketchy, since little reliable documentation as to their extent and height is available. Another problem in documentation is separating the combined effect of flooding by rainfall runoff and surf with that of sea inundation alone.

Based on narrative reports, the southern coastline of Guam is quite susceptible to flooding by passage of typhoons as distant as 200 nm south of Agana. Reports of the Inarajan-Merizo road being awash have been frequent. Inarajan and Talafofo Bays have suffered from inundation with the close

Figure 16 - The awesome force of a typhoon is evident in the accumulation of debris after a huge floating crane was driven ashore in Apra Harbor during Karen, 1962. (Official U. S. Navy photograph)

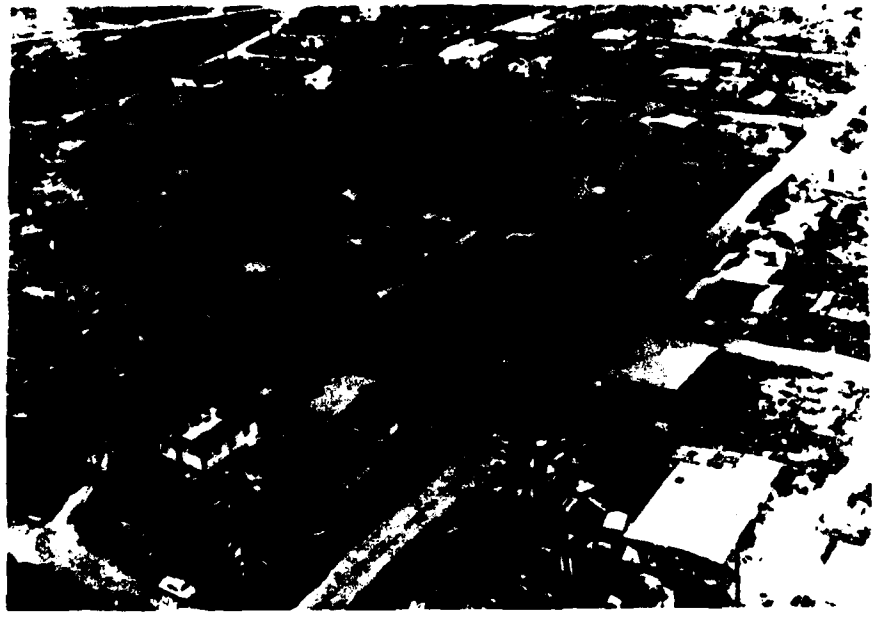

Figure 17 - While near coastal areas the effects of storm surge can be awesome, the devastation from strong winds is shown by the ruins left in the densely populated village of Agana Heights in the aftermath of Pamela, 1976. (Official U. S. Navy photograph)

passage of several typhoons during the century. During the typhoon of November 1900, the village of Inarajan was swept away with the loss of 28 lives. In Merizo, water was reported four to five feet deep during Lola (November 1957) and Cocos Island was completely inundated by Allyn (November 1949). On the western coast, the village of Agat suffered severe damage by sea action during the September 1946 typhoon and Karen (November 1962). In Agana, major inundation has occurred at least three times this century from the November 1900 typhoon and from Typhoons Karen (November 1962) and Pamela (May 1976). During the 1900 typhoon, water reached the plaza in front of the Palace near the present site of the Agana Cathedral. Both Karen and Pamela brought the sea in at least the same distance. During Karen and Pamela the storm surges washed boats, docks and debris from the Agana harbor several blocks inland, leaving fishing boats weighing several tons on Marine Drive, with sand deposits nearly a foot deep along the drive between Tamuning and Anigua. During Pamela, ten small ships and tugs which had sought refuge in Apra Harbor were either sunk or run aground, and numerous other craft were sunk or damaged (*Figure 18*). Probably the most catastrophic sea inundation on Guam was during the typhoon of November 1693 which engulfed and washed away all the existing coastal structures and vegetation!

Figure 18 - Two grounded tugs at the U. S. Naval Station, Guam. The powerful wind and wave action produced by Typhoon Pamela affected even the inner Apra Harbor. (Offical U. S. Navy photograph)

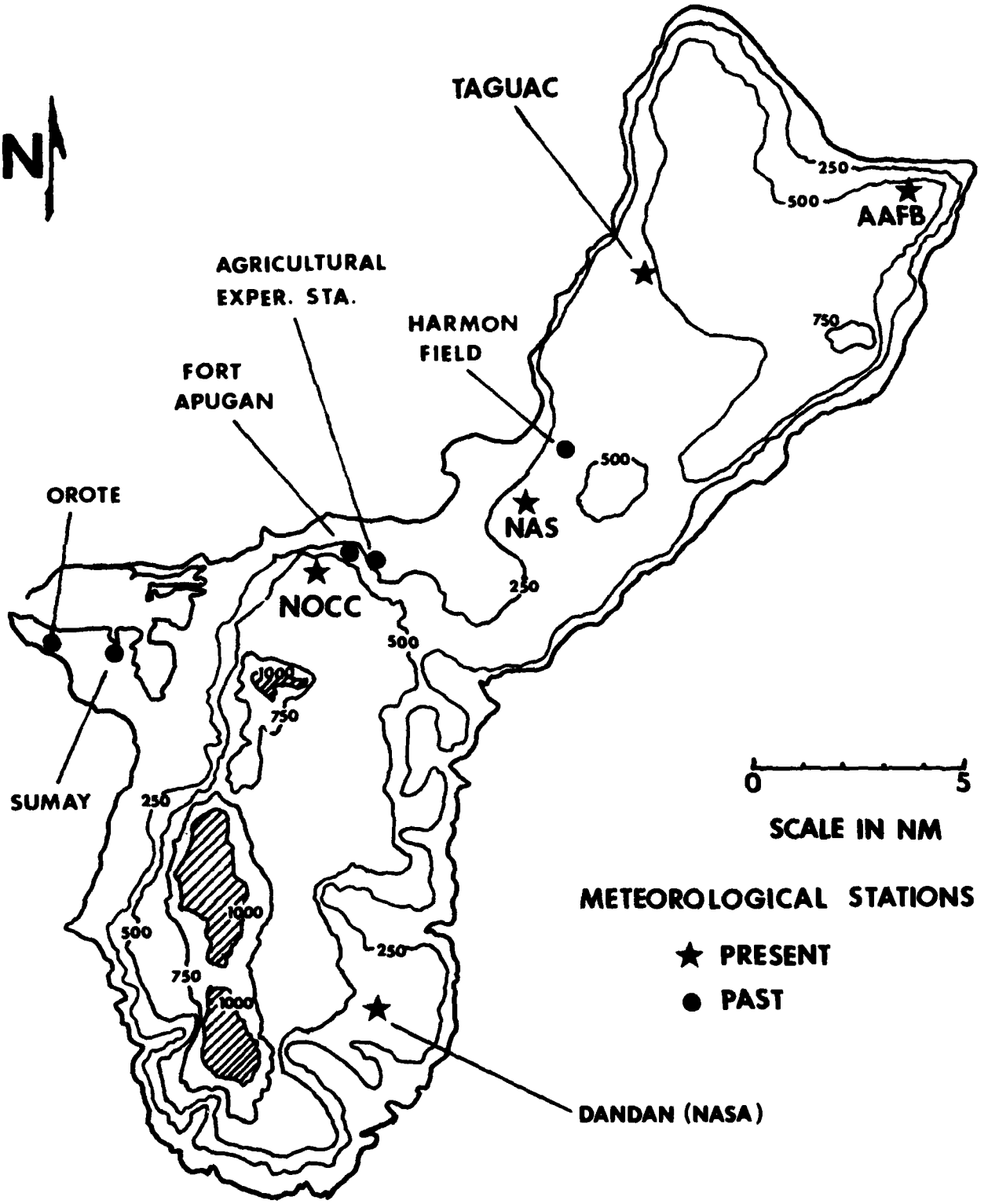

Figure 19 - Topographical map of Guam (elevations in feet above mean sea level). Present and past locations of meteorological stations are shown.

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APPENDIX A - SOME EARLY GUAM TYPHOONS

YEAR	DATE	REMARKS
1671	3 OCT*	First recorded mention of typhoon affecting Guam. "Eye passed directly over island, with most of the homes on the island toppled, as well as the church and the rectory suffering the same fate. A great many people were killed by falling debris and inadequate shelter while the damage to agricultural crops was a serious loss to the people."
1680	11 NOV	"A hurricane rose on the northern side on 11 November. Although storms were frequent in the islands, a more violent one had never been seen. It lasted two days and caused frightful disorder. Almost all the houses were toppled over, canoes smashed, trees and crops ruined. To add to the disaster, the sea became so swollen that the people were obliged to flee to the mountains."
1693	20 NOV	"In 1693 a terrible typhoon occurred. It began at dusk on the night of November 20 with a deluge of rain. The wind moved from north to south and whipped up the sea in such a manner that it seemed as if the island of Guam would be submerged. The sea broke its bounds and spread inland taking trees, houses and churches with it. Even the fortress at Agana toppled and was washed away. Those who saved themselves did so by taking refuge in the hills or by swimming about all through the night. Not a house nor building remained standing on the island. Inland from the shore the soil was covered with sand and stones left there by the subsiding sea."

Source: History of the Mariana Islands, by Father Charles Le Gobien, S. J., Paris, 1700 (translation at Micronesian Area Research Center, University of Guam)

* Data based on "the First Typhoon Recorded in Guam", translation of research by Father Paster, Guam Recorder, April 1938.

APPENDIX B - TYPHOONS AFFECTING GUAM DURING 1800's

YEAR	DATE	REMARKS
1807	7 APR	"All the houses destroyed by the strong typhoon."
1822	9 SEP	Strong typhoon affects Guam, Rota, Tinian and Saipan.
1824	11 NOV	No Details.
1831	9 NOV	No Details.
1835	7 MAR	Typhoon affected Guam and Rota.
1842	26 SEP	No details.
1847	23 MAY	"A typhoon of horrible wind destroyed a greater part of the houses. No one killed."
1848	10 AUG	"Violent typhoon causing extensive damage, flood and famine."
1855	23 SEP	"A severe hurricane accompanied by earthquakes from time to time. All native wooden houses destroyed, those of stone and tile were dismantled. The fields and plants were as if burned, being without leaves or fruit."
1857	11 APR	No details
1859	17 APR	"Strong typhoon - a ship, although having two anchors, was thrown against the reef."
1860	18 NOV	No details.
1861	23-24 NOV	"Very strong typhoon."
1864	14 FEB	"Damage to roads and houses, crops lost due to salt spray."
1868	21-23 JUN	"Roofs of houses went off, but no casualties. One ship was thrown onto another in harbor."
1870	14 NOV	"Center passed north of island, many houses, roads and bridges damaged."

YEAR	DATE	REMARKS
1872	19 AUG	"Ship Maria del Rosario thrown onto reef, three drowned."
1873	24 JUN	"Rota, Tinian, Saipan suffered much damage."
1875	7 AUG	"Destroyed houses and plantations on Tinian and Saipan."
1876	2 DEC	Agana in eye at 1500L, minimum SLP 974.9 mb "125 houses destroyed on island, many lost roofs in Agana."
1891	27 OCT	"Very strong typhoon which caused much damage, leper colony demolished. Center passage over island. The ship Yap was demolished and another ship lost."

Sources: Micronesian Area Research Center (MARC), University of Guam

1807-1842, 1848	(a)	Records of the Spanish Colonial Government in the Mariana Islands (excerpts from file at U.S. Library of Congress).
1847, 1855-1860	(b)	Cronica de las Islas Marianas, Fr. Aniceta Ibanez
1861-1891	(c)	Cronica de las Islas Marianas, Fr. Francisco Resano

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APPENDIX C - TYPHOONS AFFECTING GUAM 1900 - 1941

YEAR	DATE	REMARKS
1900	26-27 MAY	Buildings were demolished in Sumay, Agat, Merizo, and Inarajan with three bridges awash. Trees were uprooted or torn to shreds with extensive damage toll to all crops. In Apra Harbor the USS BRUTUS was torn from her moorings and blown upon the reef.
1900	13 NOV	Most severe typhoon since 1855 with center passing over southern portion of island. Pressure fell to 926.0 mb at Agana. "Agana and most of the other towns were laid in ruins, nearly all houses except of coral masonry were practically destroyed. In Agana the sea reached the Plaza in front of the Palace. A huge wall of water coming in from the sea overwhelmed the village of Inarajan, killing or drowning 28 persons." The station ship USS YOSEMITE (6000 tons) parted from her moorings and was driven upon the reefs of Apra Harbor, and later sank. Total of 34 deaths resulted from typhoon with the ruined crops being a severe economic loss.
1911	19 OCT	Center passed between Guam and Rota. Several native houses unroofed and several feet of bank along Agana beach were washed away. Some wharfs destroyed or badly damaged in Agana. Major damage sustained on Rota. Minimum pressure recorded on Rota was 946.5 mb.
1911	31 OCT	Center passed some distance south of Guam. Southern part of island affected most with many telephone poles downed. In Merizo, many houses were unroofed.
1912	26-30 AUG	Principal damage to crops by fringe effects of typhoon.
1912	15-17 DEC	Principal damage to crops by fringe effects of typhoon.
1913	17-19 SEP	Center passed north of Guam. Fringe winds damaged copra crop.
1913	10 NOV	Center passed near Rota. Minimum pressure measured at Rota was 940.1 mb, while Agana recorded 983.4 mb. Many trees and telephone poles downed and houses unroofed on Guam. Storm waves washed away Agana waterfront wharf. Several sampans were sunk or beached at Agana and all low lying areas of town were flooded.
1914	7 JUL	Center passed north of Guam. Winds gusted near typhoon force and seas in Apra Harbor were the heaviest in years. Damage to crops, buoyage, and boat channels was considerable.

YEAR	DATE	REMARKS

1914 8 OCT Center passed over Rota with a minimum pressure recorded at 925.2 mb. Although having little effect on Guam, Rota suffered considerably. A crust of salt from the ocean spray covered Rota's fields severely affecting crops, and later resulting in near famine conditions due to lack of rain during following six months.

1915 2-3 SEP Gusty winds and heavy rains from fringe of typhoon. Considerable damage done to standing crops in the northern part of the island.

1918 6 JUL Eye passed directly over Agana with a calm lasting one hour. Minimum pressure recorded in the center was 954.0 mb. Six persons were killed, thousands of persons were left homeless and property valued at many thousands of dollars received considerable damage. Hundreds of native homes were overturned while more substantial structures were either unroofed or demolished. A heavy toll was also taken in terms of the numerous telephone and power poles as well as coconut trees downed. Crop losses were considered enormous.

1918 17 SEP Gusty winds and heavy rains from fringe of typhoon passing to northeast of island. Some minor crop damage was sustained.

1919 20-21 AUG Center passed some distance south of the island with a minimum pressure of 991.2 mb recorded at Agana. Only minor crop damage reported.

1923 26 MAR Center of slow moving typhoon passed south of island with a minimum pressure of 982.0 mb (26th) and a maximum 24-hour rainfall of 4.84 inches (27th) recorded at Sumay. Winds gusted above typhoon force with the majority of the damage confined to the southern portion of the island. Bridges and roads were washed out with evidence of the sea washing for distances of a quarter of a mile inland plentiful. Several native houses were swept from their foundations, and all communication lines were downed. No loss of life was reported.

1924 1 OCT Center of typhoon passed south of Guam with winds gusting near 60 kt over southern portion of island. Minimum pressure at Sumay was 999.7 mb. Extreme rainfall occurred during passage with as much as 19 inches in 15 hrs and 28.25 inches within 30 hrs being recorded on the island. A total accumulation of 33.09 inches was measured in 48 hrs (all values at Agricultural Experimental Station, Agana). The resulting floods caused one death, the destruction of 50 buildings and a loss of hundreds of thousands of dollars. Rivers overflowed their banks sweeping away native houses, sections of roads and bridges.

1925 30 AUG Fringe of typhoon passing south of island, minimum pressure 992.2 mb recorded. No details available.

YEAR	DATE	REMARKS

1925 25 OCT Center of typhoon passed south of island with a minimum pressure of 991.5 mb recorded at Agana. Heavy waves washed along the southern coast between Inarajan and Merizo damaging roads, and wrecking bridges. Strong gusty winds were responsible for downing humdreds of trees and unroofing several houses around the southern coast.

1930 4 AUG Center of typhoon passed some distance northeast of the island. Minimum pressure of 996.6 mb was measured at Sumay with winds gusting to 36 kt and a maximum 24 hr rainfall of 4.48 inches No further details available.

1935 3 DEC Center of typhoon passed southwest of island. Minimum pressure of 998.3 mb with gusts to 60 kt was recorded at Agana. Considerable damage was reported to trees and crops but only slight damage to structures.

1940 8 JUL Center passed southwest of island. Wind gusts to 53 kt and a minimum pressure of 1001.7 mb were recorded at Agana. No significant damage reported.

1940 3 NOV Most severe typhoon since 1918. Eye estimated to have passed near southern end of island with minimum pressure of 955.6 mb recorded at Agana (1400L). Wind gusts were estimated to have reached 130 kt. Damage was heavy, in the hundreds of thousands of dollars, with one death recorded. Almost all structures on the island were either unroofed or entirely destroyed leaving thousands homeless. Hundreds of trees were downed as the strong winds took a heavy toll on planted and natural crops.

1941 3 AUG Eye of typhoon passed off northern end of the island. Minimum pressure of 969.9 mb (1230L) and a wind gust to 108 kt was recorded at Agana. A maximum 48 hr rainfall total of 12.42 inches was measured during passage. Most of structural damage was to roofs with no casualties reported. Telephone, electrical lines and many large trees were downed. Rain damage was extensive as many rivers overflowed and inundated nearby houses and washing out sections of roads. This typhoon, however, was not as severe as the typhoon in November 1940.

Sources: Period 1900-1941

1900	(a) The Guam Recorder
1911-1919	(b) The Guam Newsletter
1923	(c) "Typhoon at Guam, M.I., March 19-27, 1923" by West and Swartout, Monthly Weather Review, September 1923
1924-1941	(d) The Guam Recorder
Rota Typhoons	(e) Chronicle of Father Corbinians (translation at Micronesian Area Research Center, University of Guam)

APPENDIX D - TROPICAL STORMS/TYPHOONS AFFECTING GUAM 1945-1980
(Producing 50 kt or greater on Guam)

YEAR	NAME	DATE	REMARKS
1946	--	21 SEP	Eye of 90 kt typhoon passed midway between Rota and Guam with peak gusts estimated at 85 kts affecting Guam. Extensive damage was inflicted on temporary buildings with many quonset huts demolished. At Orote Point Naval Air Base, 70% of the aircraft sustained damage while the barracks, BOQ and repair building were almost demolished. At Harmon Field several large hangars received damage. Village of Agat was one of the most badly affected by the typhoon with 30 houses destroyed, and 30 others seriously damaged. In spite of havoc only one injury was reported. Rota received the brunt of the typhoon with trees, crops and all buildings flattened.
1948	AGNES	14 NOV	Center of storm developing to typhoon strength passed just south of Rota. Winds gusting up to 55 kt occurred on Guam but no significant damage reported on either Guam or Rota. One casualty was sustained on Saipan.
1949	ALLYN	17 NOV	Eye of severe typhoon (135 kt near center) passed 60 nautical miles south of island bringing wind gusts well over 100 kt to the island. A total of $91.1 million in damage was caused to military and non-military property. Camp Witek, a Marine base on the south-east coast received 75% damage to its temporary installations. Severe damage to native houses and crops occurred in the southern section of the island. A total of 2500 homes were damaged, and in the town of Inarajan, 60% were totally destroyed by inundation from the sea. Additionally, Cocos Island was completely inundated by the typhoon. Four major bridges were destroyed and 55% beyond use. Although several injuries were reported, no fatalities occurred.
1950	DORIS	9 MAY	Typhoon with center winds of 120 kt passed 135 nautical miles southwest of Agana with gusts of 63 kt recorded on the island. Damage was slight with a two-foot flood reported in Inarajan, and high waters washing out sections of road between Inarajan and Merizo.
1951	MARGE	11 AUG	Center of tropical storm passed 25 nautical miles south of Agana with peak gusts of 55 kt occurring on the island. Some 4 inches of rain fell within a 4-hour period (NAS); however, no significant damage by the gusty winds or heavy rains was reported.
1952	HESTER	31 DEC	Eye passed 120 nautical miles south of Guam with center winds of 100 kt and gusts to 70 kt sustained on the island. The southern end of the island reported minor damage with only a few houses destroyed. However, scores of trees were uprooted or broken off, and both the vegetable and fruit crops were lost. Heavy seas caused both the Talofofo and Ylig river bridges to be awash and several small craft were sunk at the commercial port.

YEAR	NAME	DATE	REMARKS
1953	IRMA	22 FEB	Center of tropical storm (60 kt center winds) passed 90 nautical miles south of Agana with gusts of 55 kt reported on the island. Six inches of rain was recorded in 15 hr (NAS). Only minor damage was reported to trees and crops.
1953	NINA	10 AUG	Center of developing typhoon (center winds of 65 kt) passed just offshore of the northern tip of the island with highest gust reported on the island of 57 kt. No significant damage reported with exception of uprooted trees, and high seas awash over Inarajan road and Talofofo bridge.
1953	ALICE	14 OCT	As a developing tropical storm (35 kt), Alice passed just offshore of the northern tip of the island. Peak gust recorded on the island was 56 kt on the 15th. Between the 14th and 16th, Alice drifted only 270 miles subjecting Guam to prolonged periods of torrential rains. In a period of 24 hours (14/1000L to 15/1000L) Andersen Air Force Base recorded 18.87 inches and NAS 15.48 inches. During a 48-hr period (14-16th), 32.51 inches fell at Andersen AFB, while NAS totaled 21.21 inches. Also, a severe electrical storm accompanied the passage of Alice with lightning striking Andersen Air Force Base three times, with two airmen burned. The near-record rains resulted in significant flooding with overflowing rivers washing away four bridges, isolating southern communities, and causing four drownings. Behind Marine Drive in Tamuning, all homes were inundated with depths of three to four feet reported. Large sections of Naval Station and Andersen Air Force Base were also reported under water. Property damage was estimated well in excess of $100,000.
1954	LORNA	14 SEP	Center of developing typhoon (70 kt) passed 180 miles north of Guam, causing wind gusts of 50 kt to affect the island. No significant damage was reported.
1957	LOLA	16 NOV	Eye of severe typhoon (140 kt center winds) passed 40 nautical miles south of Agana, bringing wind gusts of over 100 kt to southern portion of the island. Estimates of civilian and military loss were placed near $5 million. Damage from the wind in the northern part of the island was mainly confined to stripping roofing material from structures and broken windows; however, several elephant quonset huts were blown down (one at NAS and several in Anigua). In the southern sector of the island scores of structures were unroofed or collapsed. High seas inundated sectors (particularly Inarajan) along the southern coast with wave action damaging homes and toppling trees, while leaving portions of roads and bridges awash. Several rivers on the island overflowed and inundated nearby homes. No casualties were reported.

YEAR	NAME	DATE	REMARKS

1961 NANCY 10 SEP Eye of severe typhoon (130 kt center winds) passed 125 nautical miles south of Agana with peak winds estimated at 59 kt over southern end of island. Roads were damaged by sea action along the southern coast and 50% of crops in southern sector of island were destroyed. The northern end of the island suffered little damage. No casualties were reported.

1962 KAREN 11 NOV Most intense typhoon to strike Guam since 1900. The eye of severe typhoon (center winds 130 kt) passed over southern end of the island between Talofofo and Umatac. (Although appeared headed for Rota, during last six hours before CPA, Karen took a 20° shift to the west). Wind gusts were estimated to have reached 150-160 kt over sections of the island. Approximately $250 million in damages were sustained. Ninety-five percent of all homes were destroyed on the island, leaving 9000 homeless, 100 injured, and 9 dead. At Andersen Air Forece Base some 180 buildings were destroyed, while at the Naval Station 80% of the Ship Repair Facility's buildings suffered moderate to severe damage. Other naval buildings sustained minor to major damage with many quonset hut structures collapsed and others were wrenched from their moorings. At Apra Harbor, three ships were sunk while two tug boats and a huge floating crane were driven ashore. The sea inundated Marine drive depositing boats from the Agana boat basin as far as one block inland. The following vivid description of the damage extent is extracted from the official Fleet Weather Central report on Karen: "The central portion of the island exhibited the eerie appearance of being completely denuded. Snapped and uprooted palm trees and shrubs liken the area to the scorched effects of a forest fire. Bark was stripped off tree trunks and branches as if they had been sandblasted. Utility poles followed the same destructive pattern as poles were snapped like match sticks."

1963 OLIVE 29 APR One of the few typhoons approaching Guam from the south. The eye of this major typhoon (center winds 125 kt) passed 35 nautical miles west of Agana at a slow pace (5-7 kt). Peak gusts of 85 to 90 kt were experienced on the island. Temporary structures (quonset huts and wooden buildings) received severe damage or were destroyed in certain sectors of the island. In total 120 homes were destroyed, 1140 severely damaged, while some 60 commercial buildings were partially demolished. As a result at least 1000 people were left homeless. Many of those left homeless had been housed in tents and other temporary structures after the passage of Typhoon Karen just five months prior to Olive. Flooding by the sea was experienced in Inarajan, Merizo and Anigua. Several bridges were also awash (particularly the one over Ylig River). Total damage was estimated at $5 million with ruined agricultural crops accounting for 20% of total. No casualties were reported. The center of the typhoon shifted to a northeastward track after passing Guam. Later the eye crossed directly over Saipan on the 30th, with wind gusts estimated near 120-130 kt. Ninety-five percent of houses were badly damaged, powerlines destroyed, water system inoperative, new hospital roof, supply and public works center badly damaged. Total damage to public and private sectors was estimated near $4.4 million.

YEAR	NAME	DATE	REMARKS

1963 WENDY 11 JUL Eye passed 65 miles southwest of Agana with center winds of 85 kt, causing wind gusts of 50 kt to affect the island. Fortunately, storm was of small areal extent or significantly higher winds would have been expected. Damage was confined mainly to crops.

1963 SUSAN 24 DEC Fourth major typhoon to pass within 180 nautical miles in 13 months. Eye tracked north of Rota or 70 nautical miles from Agana with center winds of 95 kt. Wind gusts of 70 kt were estimated to have affected the northern tip of the island. No significant damage was reported on Guam. However, moderate damage was reported on Rota, Tinian and Saipan with homes suffering from 25% to 90% damage.

1964 SALLY 5 SEP Center of developing typhoon (60 kt) crossed near southern tip of island bringing wind gusts estimated near 70 kt over southern end of Guam. Several homes in southern villages were unroofed while scores of trees were downed. Some sea inundation was reported at Talofofo Bay. Majority of monetary damage was in farm crop loss.

1967 GILDA 13 NOV Eye of major typhoon (center winds 100 kt) passed over Rota or 55 nautical miles north of Agana bringing wind gusts of 60 kt to northern end of island. Winds were strong enough to destroy a large bulk of the crop production but not significant structural damage occurred. Heavy damage was sustained on Rota as some 100 buildings were demolished, resulting in 500 homeless and eight injuries, but no deaths.

1968 JEAN 11 APR Eye of severe typhoon passed 95 nautical miles northeast of Agana with center winds of 115 kt. A gust to 54 kt was recorded on the northern tip of the island. No significant damage was sustained on Guam. Jean, however, devastated Saipan with wind gusts estimated at 140-150 kt with 90% of the island's housing destroyed leaving thousands homeless, and an estimated total damage of $16 million. In spite of the damage, only one person was severely injured, and no deaths were reported.

1968 IRMA 22 OCT Center of developing tropical storm (45 kt) passed just south of Rota or 50 nautical miles north of Agana. Peak wind gusts of 65 kt swept the northern tip of Guam; however, no significant damages were reported. Some minor to moderate damage occurred on Rota and Saipan.

1968 JUDY 27 OCT Eye of major typhoon (105 kt) passed 100 nautical miles south of Agana. Peak gusts of 50 kt were experienced on the island; however, no significant damage was reported.

YEAR	NAME	DATE	REMARKS

1968 ORA 23 NOV Center of fast-moving (20 kt) tropical storm passed directly over Agana accompanied by wind gusts as high as 75 kt occurring over northern portion of the island. Damage was limited to loss of power on island, some broken windows and downed trees. The roof at the Santa Barbara School in Dededo was reported caved in. Heavy rains temporarily caused some rivers to overflow and flood bridges.

1969 PHYLLIS 22 JAN Center of weakening but fast-moving (20 kt) tropical storm passed over Agana with brief gusts of 45-50 kt experienced over northern portion of island. Rainfall from system was quite light (.48 inches in 24 hrs). No damage reported.

1971 AMY 3 MAY Eye of severe typhoon (120 kt) passed 90 nautical miles southwest of Agana. Amy's progress between the 3rd and 4th was slow (6 kt), causing prolonged gales (gusts to 60 kt) and heavy rain to affect the island with a total amount of 15.21 inches in 48 hours. Seas inundated many areas in the southern portion of the island with Inarajan reporting significant flooding and several sections of road being washed out. Damage estimates were placed near $902,000 with 80% accounted for by wind damage to crops.

1974 MARY 11-13 AUG Mary's center was located some 450 nautical miles to the northeast. However, her circulation was characterized by maximum wind bands far removed from the low pressure center. Winds gusting to gale force occurred over a period of 3 days with gusts peaking near 55 kt on the 12th and 13th. Record rainfall amounts occurred in August with 7.25 inches recorded in 24 hours as Guam lay beneath Mary's persistent outer rain bands. The persistent strong southwesterly winds were responsible for significant damage to marine interests on Guam. The CARIBIA (a 40,000 ton passenger liner being towed to Taiwan for salvage) was cut loose from her tug at the entrance to Apra Harbor, ran aground on the breakwater, and sank ($3.3 million loss). The heavy seas also took their toll on small craft (which are normally protected on the leeward side of the island in the trades) as many broke their moorings and went aground. One yacht valued at $250,000 was included among the lost vessels. Some flooding by the sea was reported around the southern and western coasts from Merizo to Tamuning. Two lives were lost due to drowning and damage estimates amounted to over $542,000.

YEAR	NAME	DATE	REMARKS

1975 JUNE 19 NOV Eye of severe typhoon (center winds 160 kt) passed within 215 nautical miles west-southwest of island causing wind gusts up to 70 kt (Andersen Air Force Base). Wave action inundated several sections of the seacoast highway between Merizo and Umatac while sections of road between Ylig Bridge and Talofofo were blocked by backed up drainage water and debris. Wind accounted for most of the damage with apparent tornadic effects experienced in the central part of the island. Mangilao was hardest hit with several homes destroyed and some structures unroofed. This severe damage appeared to be confined to a narrow path which extended westward towards Tamuning, with several other structures along the way receiving damage in addition to downed power poles, and some cars blown from their parked positions. Estimated total damage was near $1.3 million with 38% accounted for in crop loss. Twenty-nine persons were left homeless but no deaths were reported.

1976 PAMELA 21 MAY Most severe typhoon to affect Guam since Typhoon Karen of 1962. Slow progression of Pamela across the island (eye passage - three hours) rendered Pamela more destructive than Typhoon Karen. Winds in excess of 100 kt were observed for 6 hours; typhoon force winds for 18 hours; and winds in excess of 50 kt for 30 hours. Despite extensive preparation, damage to both civilian and military facilities was estimated near $500 million; however, only one death was recorded. Estimated peak winds (sustained) were 120 kt with gusts to 145 kt. NWS Taguac recorded 33 inches of rainfall during Pamela's passage, with 27 inches recorded in a 24-hour period. Ten small ships and tugs which sought refuge in Apra Harbor either sank or ran aground. After passage, Pamela continued on a northwestward track at an average speed of 10 kt and maintained its 120 kt intensity for an additional 36 hours.

1977 KIM 08 NOV Eye of a developing typhoon tracked over Guam. The duration of the eye passage was over an hour and the peak gust of 77 knots was recorded just after Kim crossed the island. The greatest damage occurred in the southern portion of the island where 22 homes were severely damaged or destroyed. The total losses associated with Kim were nearly $600,000.

1978 RITA 23 OCT Center of a very compact super typhoon passed 82 nautical miles south of Agana. Gale force winds were experienced for 10 hours or less over the island; the maximum recorded wind was 72 kt at NASA DanDan. Although high winds were restricted to the southern end of the island, rainfall amounts were light and the total damages were held to less than $700,000.

1979 JUDY 17 AUG Center of a rapidly developing tropical depression surprised Guam. Although the damage inflicted on Guam was insignificant, this tropical cyclone reminded Guam that a significant tropical cyclone can develop in a matter of hours. Approximately 10 hours after reconnaissance aircraft located a weak circulation east of Guam, the developing cyclone moved over Guam in the middle of the night and produced wind gusts over 40 kt for several hours.

YEAR	NAME	DATE	REMARKS
1979	TIP	09 OCT	Center of a developing typhoon passed 38 nautical miles south of Agana. The maximum wind observed was a gust of 68 kt at NASA DanDan. After passing Guam, Tip rapidly deepened to a super typhoon and brought sustained high seas to the western exposed shoreline for nearly a week. The total losses associated with Tip amounted to nearly 1.6 million dollars.
1979	ABBY	08 DEC	Center of an unorganized tropical storm passed 108 nautical miles south of Agana. A peak gust of 55 kt was recorded at NOCC, Nimitz Hill. No significant damage was reported with the passage of this cyclone.
1980	BETTY	31 OCT	Center of a rapidly moving typhoon passed 25 nautical miles south of Agana. Extensive flooding was reported on the southeastern portion of the island during the typhoon passage. Damage was moderate and generally restricted to the southern one-third of the island. Gale force winds occurred just prior to CPA and sustained for six hours after CPA. The highest recorded wind was 79 kt at the Naval Air Station.

APPENDIX E

TROPICAL CYCLONES (≥34 KTS) PASSING ≤180 NM OF AGANA, GUAM

NAME	DATE	CPA	MAX WND	EST MSLP	PK GUST DIR SPD	GUAM MSLP	GALE HRS	24HR RAIN	MVMT AT CPA
(none)	21 Sep 46	N 26	90	955	WSW 82@(n)	927 (h)	25	4.68	WNW 13
PEARL	01 Jul 48	SW 170	35	997	SSE 37 (n)	1002 (n)	8	1.21	WNW 15
PAT	27 Oct 48	N 115	35	997	SW 39 (a)	1003 (nf)	3	2.23	WNW 15
AGNES	14 Nov 48	NNE 40	60	980	N 65 (a)	987 (nf)	18	4.90	WNW 15
HESTER	24 Jul 49	NNW 120	55	985	SW 44 (n)	1002 (nf)	1	2.03	Looped
ALLYN	17 Nov 49	S 60	135	909	ENE 80@(n)	972 (nf)	37	4.33	WNW 12
DORIS	09 May 50	SW 135	120	922	SE 63 (a)	998 (n)	26	3.74	NW 11
KEZIA	05 Sep 50	N 135	35	997	SSW 38 (a)	1002 (a)	<½	1.33	Stalled
MARGE*	11 Aug 51	S 25	55	983	ENE 55 (n)	966 (n)	9	2.51	WNW 8
THELMA	27 Oct 51	NNE 120	65	978	SE 40 (a)	1009 (a)	5	.39	WNW 20
BESS	09 Nov 52	N 50	35	997	--- --- --	--- ----	---	2.92	WNW 16
HESTER	31 Dec 52	S 120	100	945	E 70 (a)	996 (a)	27	2.17	W 22
IRMA*	21 Feb 53	S 90	55	985	SE 55 (a)	1006 (a)	15	7.88	WNW 15
NINA	10 Aug 53	N 15	65	976	S 57 (n)	982 (a)	20	7.07	NW 12
ALICE	15 Oct 53	N 15	35	997	S 56 (a)	1001 (a)	9	18.33	W 6
IDA	24 Aug 54	SSW 70	35	997	S 44 (a)	1001 (a)	8	1.60	W 16
LORNA	14 Sep 54	N 180	70	975	W 50 (a)	977 (a)	9	2.33	W 10
TILDA	26 Nov 54	S 80	45	990	E 38 (n)	1006 (a)	4	1.58	W 9
VIRGINIA	19 Jun 57	S 100	45	993	SE 43 (n)	1005 (n)	2	.79	WNW 16
FAYE	18 Sep 57	SSW 135	105	941	E 35 (a)	1007 (n)	3	.83	WNW 9
HESTER	05 Oct 57	E 25	55	987	SW 45 (a)	993 (n)	3	3.97	S 10
JUDY*	21 Oct 57	N 125	55	985	WSW 29 (n)	---- ---	---	3.48	W 13
KIT	07 Nov 57	SSW 125	45	985	--- --- --	---- ---	---	2.90	WNW 21
LOLA	15 Nov 57	S 40	140	900	NNE 84@(n)	978 (n)	34	5.61	WNW 12
PHYLLIS	28 May 58	SW 170	105	940	SSE 37 (a)	1006 (n)	1	.91	NW 11
VIOLA*	08 Jul 58	SW 65	60	982	SE 42 (n)	---- ---	1	1.92	NW 8
GRACE	29 Aug 58	SSW 155	35	997	ESE 36 (n)	---- ---	---	.22	WNW 8
IDA	20 Sep 58	S 20	35	998	E 46 (n)	999 (n)	6	1.75	W 17
DINAH	16 Oct 59	SSW 125	90	953	N 42 (n)	1000 (n)	5	1.01	WNW 20
EMMA	06 Nov 59	SSW 120	45	993	NE 35 (n)	995 (n)	<½	2.27	WNW 10
MAMIE	15 Oct 60	NE 175	40	996	WSW 32 (n)	---- ---	---	.54	NW 11
NANCY	10 Sep 61	S 95	130	910	SSE 59 (nh)	995 (n)	25	3.68	WNW 15
VIOLET	05 Oct 61	NNW 170	65	980	SW 34 (n)	---- ---	<½	1.59	Hooking
BILLIE	23 Oct 61	SW 175	35	995	ENE 39 (a)	1001 (n)	8	2.73	SSE 9

NAME	DATE	CPA	MAX WND	EST MSLP	PK GUST DIR SPD	GUAM MSLP	GALE HRS	24HR RAIN	MVMT AT CPA
GEORGIA	19 APR 62	WSW 160	85	956	SE 39 (n)	1001 (n)	<½	1.77	SW 7
RUTH	14 Aug 62	NE 100	40	993	NW 34 (n)	---- ---	--	1.75	N 7
EMMA*	02 Oct 62	NNE 170	55	985	W 46 (n)	1001 (a)	8	3.41	Stalled
KAREN	11 Nov 62	S 10	135	908	N 125(nh)	932 (n)	28	6.32#	W 17
NADINE	08 Dec 62	N 15	45	990	E 45 (a)	991 (n)	1	2.77	ENE 7
OLIVE	29 Apr 63	W 35	130	932	SW 87(nh)	977 (nh)	52	4.86	N 7
WENDY	11 Jul 63	SW 80	80	947	E 50(nh)	999 (n)	26	3.17	SW 6
LOLA	13 Oct 63	W 30	35	996	WSW 35 (n)	998 (a)	2	4.24	Looped
SUSAN	24 Dec 63	N 75	75	948	W 61 (a)	992 (a)	36	6.09	WNW 12
TESS	20 May 64	NW 180	65	978	WSW 35 (a)	997 (a)	<½	2.03	NE 21
ALICE	27 Jun 64	SW 50	45	993	ESE 32 (n)	1005 (n)	--	.55	WNW 8
SALLY	05 Sep 64	S 10	65	976	ESE 54 (a)	998 (n)	8	2.08	WNW 20
WILDA	18 Sep 64	NNE 165	35	997	--- -- ---	---- ---	--	-----	NW 6
HARRIET	22 Jul 65	SW 30	35	995	S 40 (a)	999 (n)	10	3.75	SSW 13
VIRGINIA	13 Sep 65	NE 130	40	992	SW 35 (a)	1005 (a)	--	7.48	NW 10
BESS	28 Sep 65	NNE 150	85	966	SW 41 (a)	1001 (a)	3	2.54	WNW 9
FAYE	20 Nov 65	S 175	35	997	E 35 (a)	1006 (n)	5	1.67	W 16
JUNE	22 Sep 66	W 145	45	988	S 36 (a)	---- ---	--	2.18	S 10
THERESE	20 Mar 67	NNW 90	35	998	S 30 (a)	1001 (a)	--	1.72	ENE 12
DINAH	17 Oct 67	S 40	35	997	E 30 (a)	1005 (n)	--	1.68	W 10
GILDA	13 Nov 67	NNE 55	100	945	NW 60 (a)	981 (a)	46	5.09	WNW 10
HARRIET	19 Nov 67	NNE 100	65	978	SE 30 (a)	1007 (a)	--	1.55	WNW 11
JEAN	11 Apr 68	NE 95	115	935	NNW 54 (a)	999 (a)	44	.33	NW 9
LUCY	27 Jun 68	NNW 130	35	998	ENE 27 (a)	---- ---	--	.90	WNW 19
MARY	21 Jul 68	NE 155	40	994	S 41 (a)	---- ---	<½	2.68	NW 9
WENDY	29 Aug 68	NNE 130	85	950	--- -- ---	---- ---	--	.79	Stalled
AGNES	02 Sep 68	N 180	75	965	SW 37 (a)	---- ---	<½	1.30	WNW 11
IRMA	22 Oct 68	N 30	50	985	W 66 (a)	989 (a)	31	4.82	SE 8
JUDY	27 Oct 68	S 100	105	937	E 50 (a)	1005 (n)	13	.76	WNW 13
KIT	01 Nov 68	E 95	50	985	NW 41 (a)	1002 (n)	<½	.29	NNW 8
ORA	22 Nov 68	0	55	988	NE 77 (a)	988 (n)	8	3.18	WNW 20
PHYLLIS	22 Jan 69	0	35	1000	SE 55 (a)	1000 (a)	1	.48	W 20
IDA	16 Oct 69	NNE 90	35	998	S 36 (a)	1006 (a)	--	9.38	NW 6
PATSY	15 Nov 70	NW 90	50	987	W 21 (a)	1003 (a)	--	2.72	WSW 12
AMY	12 May 71	SSW 90	120	920	E 60 (a)	998(nh)	43	9.92	WNW 9
ROSE	09 Aug 71	NW 90	35	1000	NE 24 (a)	1006 (a)	--	1.63	WNW 10
FAYE	06 Oct 71	N 125	35	992	SE 36 (a)	1002 (a)	3	2.18	W 27
RITA	07 Jul 72	S 170	35	998	SE 40 (a)	1005 (n)	<½	2.97	W 7
BETTY	10 Aug 72	NE 150	50	985	NE 18 (a)	1006 (a)	--	1.05	NW 13
CARLA	03 May 74	NNE 105	45	989	NNW 35 (a)	1005 (a)	<½	4.39	WNW 8
POLLY	26 Aug 74	NNE 150	45	991	SW 35 (n)	1001 (a)	<½	5.14	Stalled

NAME	DATE	CPA	MAX WND	EST MSLP	PK GUST DIR SPD	GUAM MSLP	GALE HRS	24HR RAIN	MVMT AT CPA
PAMELA	21 May 76	0	120	930	unk 138 (t)	932 (n)	49	27.00	NW 7
SALLY	24 Jun 76	SW 180	35	999	SE 35 (a)	1007 (n)	--	.50	NW 14
THERESE	13 Jul 76	NE 140	130	913	ENE 40 (a)	998 (n)	<½	.82	NW 16
BILLIE	03 Aug 76	NE 105	50	988	S 30 (a)	1001 (n)	--	3.60	SW 14
FRAN	05 Sep 76	SW 30	50	985	S 30 (a)	992 (n)	12	3.18	NW 13
GEORGIA	12 Sep 76	S 45	35	995	E 30 (a)	997 (n)	--	1.34	WSW 12
LOUISE	31 Oct 76	SSW 180	45	993	ESE 37 (a)	1006 (a)	10	1.25	WNW 14
KIM	08 Nov 77	N 5	60	979	SE 77 (a)	978 (a)	7	4.44	NNW 15
MARY	30 Dec 77	SSE 145	55	978	ENE 39 (a)	1008 (a)	12	0.57	WSW 14
CARMEN	11 Aug 78	N 130	45	989	--- -- ---	---- ---	--	4.21	SSW 4
FAYE	28 Aug 78	ENE 60	35	998	NW 16 (a)	1004 (a)	--	.82	NNW 10
RITA	23 Oct 78	S 80	150	899	ESE 72 (d)	1005 (n)	8	1.10	W 17
ALICE	10 Jan 79	S 85	70	973	ESE 45 (nh)	1003 (a)	12	1.22	W 11
JUDY	17 Aug 79	SSW 5	35	998	NE 60 (n)	997 (n)	3	2.35	NNW 15
TIP	09 Oct 79	S 40	60	974	ENE 68 (d)	994 (d)	15	10.14	W 14
ABBY	08 Dec 79	SSW 110	35	996	ESE 55 (nh)	1000 (n)	<½	1.01	WNW 9
ORCHID	09 Sep 80	N 75	35	998	SW 34 (n)	998 (a)	1	6.34	NNW 11
WYNNE	06 Oct 80	ENE 60	45	994	WSW 25 (a)	1005 (a)	--	1.72	NW 10
BETTY	31 Oct 80	S 25	70	984	ESE 79 (n)	933 (n)	11	1.78	WNW 21
DINAH	33 Nov 80	NNE 125	100	950	WSW 23 (a)	1004 (a)	--	.60#	NW 16

CPA — Closest point of approach from Agana in nautical miles (nm)

MAX WND — Estimated maximum sustained (one-minute) surface wind speed in knots (kt) near the tropical cyclone's center

EST MSLP — Estimated central minimum sea level pressure of the cyclone in millibars (mb)

PK GUST DIR SPD — Direction and speed of peak gust observed on Guam
Legend: @ anemometer failed, a Andersen AFB, d NASA DanDan, h Harmon Field n Naval Air Station, nh Nimitz Hill (NOCC), t Tagauc (NWS)
see *Figure 19* for location of observation sites

GUAM MSLP — Minimum sea level pressure observed on Guam during passage on cyclone
Legend: same as above

GALE HRS — Duration in hours of gusts to gale force (≥34 kts), normally at Andersen AFB

24HR RAIN — Maximum 24-hour rainfall observed on Guam during passage of cyclone.
Sites used: North Field (1946-49), Andersen AFB (1950-56), Taguac (1957-80)
measured on the 12th, no data available for the 11th

MVMT AT CPA — Direction and speed of movement of the tropical cyclone at CPA.

* Originally classified as a typhoon (≥64 kts) at CPA to Guam. Available reconnaissance data was reevaluated in 1975 and MAX WND values were adjusted accordingly.

APPENDIX F

TROPICAL CYCLONES (≥ 34 KTS) PRODUCING GUSTS TO GALE FORCE (≥ 1 HR) BUT PASSING OUTSIDE OF 180 NAUTICAL MILES OF GUAM

NAME	DATE	CPA	MAX WND	EST MSLP	PK GUST DIR	PK GUST SPD		GALE HRS	REMARKS
JEAN	21 Dec 47	SSW 300	45	900	ENE	43	(a)	2	
KIT	28 Jun 53	SW 345	85	956	E	35	(a)	3	
TILDA	16 Apr 59	SSW 230	105	938	ENE	38	(n)	4	
OPHELIA	30 Nov 60	SSW 200	80	965	E	39	(n)	2	
OPAL	11 Dec 64	SW 410	65	977	E	43	(n)	1	
OLGA	28 Jun 70	SW 240	35	997	E	42	(a)	3	
MARY	12 Aug 74	NE 455	40	989	SW	57	(a)	67	24HR RAIN - 7.36
GLORIA	04 Nov 74	SW 450	55	983	SE	43	(a)	4	
JUNE	19 Nov 75	WSW 215	155	885	SE	70	(a)	25	24HR RAIN - 3.16 GUAM MSLP - 997 (n)
KATHY	20 Jan 76	SW 355	40	996	ESE	38	(a)	3	
VIOLA	18 Nov 78	SSW 195	45	989	ESE	45	(a)	1	
VERNON	30 Sep 80	NE 600	75	960	SW	37	(a)	2	24HR RAIN - 6.09

See Appendix E for an explanation of columns and coding.

APPENDIX G

DEFINITIONS

Center - the vertical axis or pivot of a tropical cyclone. Usually determined by wind, temperature and/or pressure.

Cyclone- a closed atmospheric circulation rotating about an area of low pressure (counterclockwise in the Northern Hemisphere). In general terms, cyclone is used in the text to refer to that group of tropical cyclones which have attained or are developing maximum sustained winds of at least 34 knots.

Eye - a description of the central area of a tropical cyclone (frequently a typhoon) when it is more than half surrounded by a wall cloud.

Knot(s)- (kt) a unit of speed equal to a rate of one nautical mile (approximately 6,076 feet) per hour.

Maximum sustained wind- the maximum surface wind speed averaged over a one-minute period of time. Peak gusts over water average 20 to 25 percent higher than sustained winds.

Millibar- (mb) a unit of measure of atmospheric pressure equal to 1,000 dynes per square centimeter. The standard atmosphere is approximately 1013.2 mb at sea level.

Monsoon trough- the near equatorial trough of the summer season in the western North Pacific.

Nautical mile- (nm) a unit of measurement (approximately 6,076 feet) equal to 1.15155 statue (common) miles.

Near equatorial trough- a trough, usually within 15 degrees of latitude of the equator, where the trade winds of one hemisphere (northern or southern) turn into the opposite hemisphere (counterclockwise in the Northern Hemisphere. This trough is considered to be a prime breeding ground for tropical cyclones.

Ridge- an extension of relatively high atmospheric pressures in which the winds move clockwise in the Northern Hemisphere around its periphery and are frequently light near its axis. Generally, a fair weather phenomena.

Sea level pressure- the weight of the atmosphere at sea level. Although 1013.2 mb is considered to be normal at sea level, the tropical latitudes usually have lower pressures (1010 to 1004 mb is common).

Storm- in general terms (in the tropics), this would refer to that group of tropical cyclones which have attained sustained winds of at least 34 knots.

Super typhoon - a typhoon in which the maximum sustained surface wind is 130 knots or greater. 130 knots is approximately twice the minimum typhoon intensity (64 knots).

Trade wind - an enhanced flow of northeasterly winds in the Northern Hemisphere which frequent the subtropical and occasionally the tropical latitudes.

Tropical cyclone - a non-frontal low pressure system of synoptic scale (usually 100 nm or more) developing over tropical or subtropical waters and having a definite organized circulation. In this text, this term is further used to describe those which have attained sustained winds of at least 34 knots.

Tropical depression - a tropical cyclone in which the maximum sustained surface wind is 33 knots or less.

Tropical storm - a tropical cyclone with maximum sustained winds in the range of 34 to 63 knots inclusive.

Trough - an extension of relatively low atmospheric pressures in which the winds move counterclockwise in the Northern Hemisphere and frequently are light near its axis. Generally associated with unstable weather.

Typhoon - a tropical cyclone in which the maximum sustained surface wind is 64 knots or greater. Same classification as a hurricane.

Wall cloud - an organized band of cumuliform (vertically developed) clouds immediately surrounding the central area of a tropical cyclone. The wall cloud may entirely enclose the eye or only partially surround the center.

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